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THE DEHYDRATION OF VEGETABLES

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THE DEHYDRATION OF VEGETABLES[1]

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INTRODUCTION

This bulletin is intended as a reference and operating manual for those interested in vegetable dehydration. It replaces the mimeographed report by Cruess and Mrak (1941)[4], issued also as a Quartermaster Corps Special Subsistence Bulletin, and summarizes recent investigations designed to improve efficiency in operation and, more especially, the quality of the finished product.

At present the U. S. Army and the Lend-Lease Authority are purchasing most of the dehydrated vegetables produced in this country. Though the 1942 output was considerable (about 70,000,000 pounds), several times as much will be needed in 1943. On this account vegetable-dehydration facilities are being rapidly expanded.

Historical Notes.—The drying of foods has been practiced for centuries. Figs, raisins, other fruits, and meats preserved in this way were probably used by the ancients. In England green peas in the pod, still on the vines, and not fully mature, are slowly dried in the windrow, in the shock, or under cover without artificial heat. Sweet corn cut from the cob was dried in the sun or in an oven by early American settlers, a custom still followed on many farms.

According to Prescott (1919) desiccated vegetables, compressed into briquette form, were used—though sparingly—to prevent scurvy among Union troops during the Civil War. With the drying methods then available, however, the vegetables were probably devoid of vitamin C, and consequently would have had no antiscorbutic value. Prescott also mentions the desiccated soup vegetables used successfully by the British army during the Boer War.

During World War I, according to Nichols (1925) and his associates, the number of pounds of dehydrated vegetables shipped to the U. S. Army overseas was as follows: potatoes 6,437,430 pounds; onions 336,780; carrots 214,724; turnips 56,224; and soup mixture 1,860,000—a total of 8,903,158 pounds.

Many of these products were dehydrated in California. Except for the potatoes, the vegetables were usually not blanched; and all were dried to the moisture content that the Army required—below 10 per cent.

Shortly after World War I, returning veterans reported informally to the present authors that these vegetables as served them abroad had been poor in flavor and often tough. According to one member of the expeditionary forces in northern France, the dehydrated products were first used in his division in September, 1918, when fresh ones were not obtainable. They were served at three meals a day, including breakfast. Since they retained little of their fresh flavor, they were often mixed in a stew with canned corned or roast beef, or salmon, to render them more palatable. The toughness and the lack of flavor resulted in large measure from failure to blanch the vegetables before drying.

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[4] See "Literature Cited" for complete citations, which are referred to in the text by author and date of publication.

After World War I, especially in 1919 and 1920, attempts were made to interest the civilian population in dehydrated vegetables. One California firm developed a considerable mail-order business; another built several large plants and advertised in the leading journals; and two large plants marketed pumpkin flour for several years. In Pennsylvania and Ohio rather large quantities of sweet corn were dehydrated and sold.

Late in the 1920's there was a flurry of interest in dehydrating Jerusalem artichokes for use by diabetics. In that decade, also, some interest was aroused in breads and bakery goods "vegetized" with powdered dehydrated vegetables; but these products were never a commercial success.

More lasting has been the production in recent years of flaked onions, powdered garlic, powdered onions, celery, and chili for flavoring meat products and certain canned foods, as well as for cooking for institution and home use. Various specialties have been reported by Cruess, Friar, and Balog (1942). Powdered vegetables for pharmaceutical use have also been dried.

Limited quantities of vegetables are still dehydrated and packed primarily for campers. Recently, dehydrated mixed vegetables and powdered vegetables for soup have become fairly popular among civilians. For additional information, see reports by Cruess (1919, 1938, 1943).

Present Status of Vegetable Dehydration.—In 1942 the Quartermaster Corps purchased considerable quantities of dehydrated white potatoes, cabbages, onions, and carrots, with some beets, sweet potatoes, and rutabaga turnips. Potatoes constituted more than 50 per cent of the total. In May, Colonel Paul P. Logan placed the Army's needs for dehydrated vegetables for that year at about 25,000,000 pounds; and in October he stated that the Army could use a much greater quantity if it were available. Most of the 1942 output came from California, Washington, Idaho, and Oregon, where many fruit dehydraters are available for conversion into vegetable dehydraters or where, as in Idaho, much excellent raw material (potatoes) can be procured. In recent months, dehydraters have been built or are being built in New York state, in several parts of the South, and in the Middle West.

In California there are about twenty such plants in operation, the majority being converted prune, pimento, and grape dehydraters. In addition, several large establishments have been built expressly to dry vegetables.

Informal reports from overseas indicate that dehydrated vegetables are often unsatisfactory. Several reasons may be advanced. Off flavors and odors may have developed because of inadequate blanching or, more likely, insufficient drying—for example, leaving cabbage at 7 per cent moisture, instead of below the present specification of 4 per cent. Prolonged storage, for 6 to 8 months, especially at tropical temperatures, also causes marked deterioration. It may be doubted whether much of the food has been consumed in less than 4 to 6 months from the time it was dried. While many of these difficulties can be surmounted by improved handling, it will probably be necessary to resort to sulfuring, where tropical shipments are contemplated.

Before the war, dehydrated soup vegetables in small pliofilm (a rubber hydrochloride) bags, encased in aluminum foil, were moderately popular. Now they are packed in cellophane encased in lead foil. Chicken noodle soup in similar packages, although not dehydrated, has done much to popularize

vegetable soup bases in dry form. At least one company is producing dried tomato soup for civilians as well as soldiers; and another makes powdered tomato cocktail for preparing a beverage.

With the shrinkage of the tin supply, the Federal Government will probably require that soups and some other foods be dehydrated instead of canned. By the end of the war we may also see corn, peas, spinach, and canning fruits dehydrated for the civilian market. Nearly all large canning companies are considering that eventuality.

Properties of Satisfactory Dehydrated Vegetables.—Dehydrated vegetables should have a low moisture content, usually under 5 per cent, to minimize the deterioration in color, odor, and flavor caused by oxidative and other chemical changes. They should be free from scorched flavor and the darkening caused by too severe heat treatment. They should be practically free from blemishes and from unfit raw material (decayed, unripe, scorched, and overripe specimens). In water they should refresh quickly and satisfactorily, assuming the original shape and appearance of the product as placed on the trays before drying. They should cook quickly in boiling water and when ready to serve should be tender (not tough nor oversoft), retaining much of their original odor and flavor. When packed they should be safe from insects, moisture, and air—preferably in a hermetically sealed container and under vacuum, or in inert gas.

To these requirements there are some exceptions. Dehydrated tomatoes, for example, do not regain their original size and shape on refreshing, though they keep their color and flavor for a few months if lightly sulfured before dehydration. Powdered, drum-dried, or spray-dried tomato products are fairly satisfactory. Potatoes keep well in packages that contain or admit air. Carrots and cabbage, being the most susceptible to deterioration caused by oxygen, are packed in vacuum or inert gas; or cabbage may be sulfured before drying. Factors affecting quality have been discussed by Davis, Eidt, MacArthur, and Strachan (1942).

Advantages and Disadvantages of Dehydrated Vegetables.—Dehydration greatly lessens the weight, reducing root vegetables to about one fifth of their fresh weight, leafy vegetables and tomatoes to one fifteenth or less. The bulk, especially if the dehydrated products are compressed before packaging, is much less than that of other forms.

One cargo ship can carry dehydrated vegetables equivalent to 5 to 15 shiploads of the fresh or the canned—an important consideration during the shortage of ships.

The dehydrated vegetables do not require refrigeration during shipment or storage. Because of the reduced weight and volume, less packaging material is needed per unit of food. Tin containers need not be used—a great advantage during the scarcity of tin.

Although their nutritive value is not much impaired by dehydration, most dehydrated vegetables after refreshing and cooking are not equal to the cooked fresh ones in flavor and texture. Usually, too, a somewhat longer period is required for cooking.

On prolonged storage in air, vacuum, or inert gas (particularly at temperatures above 70° to 80° F), most dehydrated vegetables undergo undesirable

changes; some, especially carrots and cabbage, deteriorate rapidly in air and change in flavor, odor, and color. If permitted to absorb moisture, they deteriorate even faster. Also, they are highly susceptible to insect attack if packed in ordinary dried-fruit cartons. The daily use of dehydrated vegetables may make the diet monotonous and lead to a mounting dislike.

The relative weights of several fresh vegetables prepared for dehydration or for canning, with the corresponding weights of the canned and the dehydrated products, appear in table 1. These values are based on data from dehydration experiments and on estimates of the weights of canned vegetables, based on average yields of the canned.

TABLE 1

COMPARISON OF WEIGHTS OF CANNED AND DEHYDRATED VEGETABLES; FROM 1,000 POUNDS OF THE PREPARED FRESH VEGETABLES*

Vegetable	Canned and packed; approximate weight in pounds	Dehydrated and packed; approximate weight in pounds
String beans	2,200	200
Cabbage	1,700	150
Carrots	1,960	200
Corn	2,000	400
Onions	2,000	180
Peas (shelled)	2,165 (no. 2 cans)	250
Potatoes	2,000	400
Spinach	1,650	155
Sweet potatoes	1,600	300
Tomatoes	1,500	85 (powdered)

* The vegetables are canned in no. 2½ cans unless otherwise indicated, and the dried vegetables are loosely packed in 5-gallon cans.

In the table the values are only approximate: the weights of the canned and the dehydrated products from 1,000 pounds of the prepared fresh will vary materially with such factors as composition of the raw material, size of the cans, weight of the packing cases, and compression or noncompression of the dried vegetables. A compressed product requires fewer cans and wooden cases, and offers a corresponding saving in packed weight and volume.

GENERAL CONSIDERATIONS

Before building and equipping a vegetable dehydrater, one should carefully consider certain questions. Several of these are suggested in the next few paragraphs.

Choice of Location.—If rail transportation, labor supply, fuel supply, and similar factors are favorable, the plant should be near the source of the raw materials. Shipping Idaho potatoes to Oakland, California, or Imperial Valley cabbage to Sacramento to be dehydrated is uneconomical, except under special conditions, and wasteful. On the whole, the coastal counties are better adapted than the hot interior valleys to most truck crops; but San Joaquin and Imperial valleys grow very satisfactory winter carrots and cabbage. The Sacramento and San Joaquin Delta grows certain truck crops such as celery, onions, and sweet corn; but dehydrater operators consider potatoes from the Delta

less satisfactory than those from Idaho, Nevada, and the Klamath Lake and Tule Lake districts.

The coastal counties from the San Francisco Bay area south to the Mexican border are truck-crop producers. As the growing season there is longer than in the hot interior valleys, almost year-round operation is possible.

Freshness of Raw Material.—As in canning or freezing, all leafy vegetables, peas, string beans, and other green vegetables should be garden fresh. Harvested spinach rapidly loses its vitamin C on standing. In peas the sugar is quickly lost after the pods are picked or after mechanical shelling.

Potatoes, sweet potatoes, onions, and cabbage can be kept for a short time without serious deterioration before drying, but fresh carrots do not store well.

Use of Culls.—Cull vegetables are not suitable; U. S. No. 2 products, if carefully sorted and used soon after harvest, are satisfactory. Too often vegetables culled from those intended for the fresh market contain rotten or wormy material that is apt to contaminate the sound, wholesome portions. Losses in trimming, peeling, and sorting are excessive; labor is costly; and the dried product is inferior.

Production of Vegetables for Drying.—The dehydrater operator, in order to secure enough good raw material in the proper sequence, must either grow the needed vegetables or contract with nearby farmers for the acreage needed.

The University of California through its Truck Crops Division at Davis has issued bulletins, circulars, and other information on production, and is always glad to advise growers of crops for dehydration. Operators should utilize this service because commercial vegetable production is difficult for the inexperienced. The dehydrater usually cannot be operated satisfactorily and economically with vegetables purchased on the open market after the season has begun. Although this fact should be self-evident, some have disregarded it to their subsequent regret.

Effect of Plant Investment on Drying Cost.—In the present emergency, or for drying one or two products during a short season in normal times, expensive plant and equipment are not justifiable. The plant should, of course, be efficient; but costly unessentials should be omitted. Needlessly expensive building materials should not be used. Often, serviceable secondhand processing equipment and fans can be found. For vegetable dehydration in wartime it is often advisable to rent an existing fruit dehydrater for the 9 to 10 months a year when it is not being used for fruits.

Depreciation, interest on investment, taxes, and other overhead charges affect the total expense of drying. According to a survey made by Cruess and Christie (1921), the cost of plant and equipment for dehydrating in 1919 and 1920 ranged from $480 to $4,167 per green ton daily capacity, and the average cost was below $1,000.

The fixed charges on plant investment per dry ton of fruit dried per season ranged from $5.10 to $40.01, based on interest at 7 per cent, depreciation at 10 per cent, insurance at 2½ per cent of one-half valuation, taxes at 4 per cent of two thirds of value, and an operating season of 60 days.

Even at the present high cost of construction it should be possible to build a forced-draft dehydrater (complete with cars, trays, tracks, and shed over tunnels) for not more than $1,000 per green ton per day capacity.

For drying vegetables the cost of steam boiler, peeling machinery, blancher, sorting belts, and other accessory equipment may equal that of the dehydrater, trays, and trucks.

If a fruit dehydrater is taken over, the main investment will be for steam supply and preparation equipment. New trays will be needed because wooden trays previously used for fruit will stain the vegetables. For a plant handling 10 tons of fresh vegetables a day, about 1,000 trays 6 × 3 feet in size are needed. If made of wood, each tray would probably cost not less than $1.00. The other principal items are steam boiler, peeling equipment, sorting belts, rotary spray washers, a machine to cut sliced, cubed, or shoestring pieces, and apparatus for unloading trays of the dried product and for packaging. Several California plants have either built much of this equipment or used secondhand apparatus.

Advantages and Disadvantages in Adapting Fruit Dehydraters for Vegetable Use.—At present carpenters and other skilled artisans are scarce or unobtainable except in the defense industries. Building materials also are on priority, costly, and difficult to obtain. For these reasons most of the vegetable dehydraters now available in California are those also used by fruit growers for drying prunes, grapes, or apples in season. As a rule they have proved reasonably efficient.

Their advantages are that they are virtually ready, require no investment in dehydrater building, and are usually of standard counter-current tunnel and truck construction, which has been satisfactory for both fruits and vegetables.

Their disadvantages are that they are often on farms several miles from the nearest city and railroad; generally lack facilities for disposal of waste putrescible liquids; often have no sheds or other buildings for preparing the raw material and storing the dried; sometimes have inadequate water supply; and usually lack a steam boiler for blanching. Also there are rather few large plants of 25 or more fresh tons' capacity per day in locations well suited to vegetable growing.

Locating Dehydraters in Canneries.—Much of the average fruit-and-vegetable cannery's equipment is adaptable for preparing vegetables for dehydration, and its warehouse for packaging and storing the dried product. Its plentiful steam supply is a great asset. Its lye-peeler for peaches is also satisfactory for potatoes and carrots. Sometimes its steam-scalder, used in peeling tomatoes for canning, will serve also to blanch vegetables. Some of the cannery fruit dicers, sorting belts, and spray washers can also be utilized. A great asset of the cannery lies in its facilities for sewage disposal.

Sewage and Waste Disposal.—As just indicated, the disposal of putrescible fluid wastes from the dehydrating plant is a serious problem. There are also solid wastes, such as peelings, cores, and leaves; but since these have value as stock feed, they are much more readily disposed of than the liquid wastes, such as wash water from the peeling machines and spent lye solution from the lye-peelers. These liquids decompose quickly, evolving obnoxious odors. Often, if run into vineyards or orchards, they poison the vines or trees. Several dehydraters have been closed by federal or state authorities because their liquid wastes, running into ditches or fields, had become a public nuisance. Considerable starch is present in the wash water from potato peelers and the rinse

water from cut potatoes. Although highly fermentable and putrescible, it has value. If collected by passage of the wash water through shallow settling tanks, it can be used as stock feed; or it may be washed and dried to make starch for industrial purposes, such as laundering.

If the dehydrater is too isolated to be connected to a city system, a satisfactory private sewage-disposal plant must usually be provided. Such a plant should be built by an experienced contractor, who should consult the State Board of Health Sanitary Engineer.

If the dehydrater is far from the city, if there are no nearby neighbors, and if the soil is deep and porous, the waste liquid can sometimes be spread to a shallow depth in large checked spaces in a nearby field. By using the checked spaces intermittently, thus allowing the liquid to evaporate and percolate into the soil, the operator may dispose of the waste rather satisfactorily. The ground should be cultivated between periods of use.

For efficiency in dehydration, certain basic principles should be understood. The more important of these are presented in the following paragraphs.

GENERAL PRINCIPLES OF DEHYDRATION

Constancy of Weight and Energy.—According to the physical laws of conservation, neither matter nor energy can be created or destroyed. The weight of the fresh vegetable placed in a dehydrater is therefore completely accounted for in the water lost as vapor, in the dried product, and in minor incidental losses. Similarly the heat input and outgo are equal. Though the sole function of the heat is to evaporate the water rapidly, incidental losses here are considerable because the vegetable dry matter, the trays, and the tunnel itself must all be heated at the same time. Heat is wasted also in the hot spent air and in radiation from the walls of the dehydrater. The heat required for all these factors will be estimated in a later section.

Latent Heat of Vaporization.—One B. t. u. (British thermal unit) is the heat required to raise 1 pound of water 1° F; the heat required to change water to vapor without change of temperature is called its "latent heat of vaporization." To raise 1 pound of water from 60° F to the boiling point (212° at sea level) requires only $212 - 60 = 152$ B. t. u. of heat. To evaporate it after it reaches the boiling point, however, requires about 970 B. t. u., or nearly seven times as much as required to bring it to evaporation temperature.

When liquid evaporates from one's skin in a breeze, cooling is experienced because the latent heat of vaporization comes from the skin and from the flesh beneath. This example illustrates a general rule: unless the heat is supplied directly to vaporize the water, it is taken from the surroundings, and even from the liquid itself.

Effect of Moisture Content on Heat Requirement for Drying.—The output per day of dry product from a drier increases rapidly with decrease in the moisture content of solids. For example, to dry 100 pounds of a raw product of 50 per cent moisture content, one would need to evaporate only 50 pounds of water to produce 50 pounds of completely dry food. To dry a food of 90 per cent moisture content, on the other hand, 90 pounds of water must be removed for 10 pounds of dry product. About nine times as much heat would be required in the second case as in the first, per pound of dry food.

Prepared potatoes of 80 per cent moisture would give 2 pounds of completely dry product per 10 pounds of raw, while prepared cabbage of 95 per cent moisture would give only ½ pound of dry per 10 pounds of fresh; 5 pounds of the prepared potatoes or 20 pounds of the prepared cabbage would be required to produce 1 pound of the dry.

Assuming that about 1,100 B. t. u. of heat are required to evaporate 1 pound of water under the conditions existing in vegetable dehydration, there would be required for producing 1 pound of completely dry potatoes about 4,000 B. t. u.; for 1 pound of completely dry cabbage, about 19,000 B. t. u.

Functions of Air in Dehydration.—In most vegetable dehydraters the flowing air carries to the product the heat units required for vaporizing the moisture and removes the resulting moisture vapor.

Liquids can be vaporized in one of two ways: *isothermally,* that is, at constant temperature, as in boiling, where heat is supplied continuously; or *adiabatically,* where the medium (in this case heated air) gives up part of its heat to vaporize the liquid and is thereby cooled. The vaporization of water in a forced-draft dehydrater is essentially adiabatic. The minimum amount of heat required to evaporate the water at a desired rate can be accurately calculated. The second calculation, to determine the air required for removing the water vapor, is in some respects artificial, the vapor in a given space being virtually independent of the presence or absence of air. Since, however, the air is continuously flushing out the water vapor from the dehydrater, so that more water can be vaporized in that space, it is convenient to talk of the moisture-carrying power of the air.

Calculation of Air Requirements.—Two general methods have been used for calculating the air requirements.

Ridley's method has been widely used (Christie and Ridley, 1923; Nichols and co-workers, 1925; Chace and co-workers, 1941). Ridley (1921) gives the following trial calculations of air requirements for dehydrating a food. Taking the weight of 1 cubic foot of air at 60° F as 0.0761 pound and the specific heat of air at constant pressure as 0.2375, the amount of heat required to raise 1 cubic foot of air 1 degree is equal to 0.0761×0.2375, or 0.01807 B. t. u. Conversely, 1 cubic foot of air dropping 1 degree would release 0.01807 B. t. u.

Assume that the atmospheric air is at 60° F; that it is heated to 160°, before entering the drying tunnel; and that it leaves the drying tunnel at 120°. Evaporation may be assumed to take place at the wet-bulb temperature—in this case about 90° to 95°. Because the wet bulb is virtually constant and is normally within this range, the heat requirement to evaporate the water is usually taken to be 1,080 B.t. u. Then the cubic feet of air needed to evaporate 1 pound of water will be $\frac{1080}{0.01807} = 60,000$ cubic feet, approximately, dropping 1 degree; or 1,500 cubic feet, dropping 40 degrees. The air is measured at 60°. Suppose further that 900 pounds of water per hour—that is, 15 pounds per minute—is to be evaporated, and the temperature drop is 40 degrees F. Then $15 \times 1500 = 22,500$ cubic feet, the minimum volume of air needed for evaporating 15 pounds of water per minute under these conditions. In addition, however, considerable heat is needed to raise the cars and trays to 160°. Suppose the food has a drying ratio of 4:1; then in 24 hours about 14.4 tons of raw

material would be handled. As experience shows, about 400 pounds of trays and cars would pass through the tunnel per hour for this daily capacity; and in this case there would also be 300 pounds per hour of dry food leaving the drier at 160°; or the total for cars, trays, and dried food per hour is 700 pounds. Assuming an average specific heat of 0.3, the B. t. u. loss would be $700 \times 0.3 \times 100$ or 21,000 B. t. u. per hour, or 350 B. t. u. per minute, which will require $\frac{350}{0.01807 \times 40} = 486$ cubic feet of air per minute. The full temperature drop of 40 degrees is not, however, available in this case. We may safely assume that it is only 20 degrees; if so, the volume of air required to meet this B. t. u. loss would be doubled, and would then be 972 cubic feet per minute.

The total minimum air required to furnish heat for drying the food and for heating the trays, cars, and dried food then becomes $22{,}500 + 972 = 23{,}472$ cubic feet per minute.

Since additional heat is lost by air leakage, by radiation from the walls, and by opening the tunnel to remove the cars of dry food and to admit loaded cars, one should probably increase the above estimate by at least 10 per cent, making the total minimum air volume required in this case $23{,}472 + 2{,}347 = 25{,}819$ cubic feet (roughly 26,000 cubic feet) per minute. This figure agrees well with practical observations.

The second method utilizes a humidity chart prepared by the Institute of Chemical Engineers.[5] In the pioneer calculations (in 1899) of Hausbrand (1912) a cumbersome procedure was adopted to relate the exhaust temperature with the final humidity. The difficulty was overcome by Grosvenor (1908), whose chart showed the uptake of moisture by air at different humidities as it cooled adiabatically.

The theory is discussed in Walker, Lewis, and McAdams' (1923) text. In the chart mentioned (illustrated also in part in figure 1) the horizontal scale shows temperatures ranging from 30° to 230° F; the vertical scale, the pounds of water vapor associated with 1 pound of dry air, when saturated (that is, at 100 per cent humidity). If air at 160° has a dew point temperature of 60°, we read from the 100 per cent saturation curve, at 60°, that 1 pound of dry air has associated with it 0.011 pound of water vapor. The same condition must obtain, therefore, with 1 pound of this air heated to 160° F, as water has neither been added nor removed. If this air is cooled adiabatically to 120° in contact with water, we merely follow the diagonal "adiabatic" cooling line from 160° with 0.011 pound water vapor to 120° and find that about 0.02 pound water vapor is now associated with the 1 pound of dry air; in other words, a moisture pickup of 0.009 pound has resulted from the cooling. Two other curves, the volume of dry air versus temperature, and the saturated volume versus temperature, permit us to change to cubic feet of air; and if the air velocity is also known, the total heat involved can be calculated together with the moisture evaporated.

Van Arsdel (1942) makes use of a convenient approximation, sufficiently precise for control purposes, that when a pound of air picks up 0.001 pound of water, the air cools about 5 degrees Fahrenheit. Thus he calculates that 3,200 pounds, or about 51,000 cubic feet of air per minute, is required to evaporate

[5] Obtainable for a nominal sum from Reinhold Pub. Co., New York, N. Y.

from a food 32 pounds of moisture per minute, if the temperature drop of the air used in drying is 50 degrees.

By the Ridley procedure the calculated air requirement would be about 47,400 cubic feet, which is fair agreement.

Recirculation of Air.—If the exhaust air is discharged at 120° F, only two fifths of the heat is utilized in evaporating water, as we may see from the

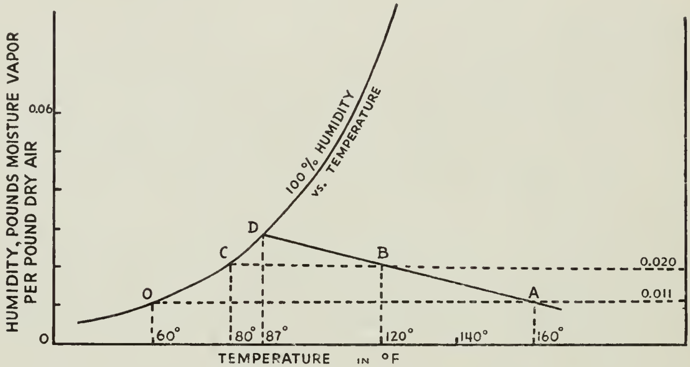

Fig. 1.—Diagram illustrating the relation of temperature to humidity, based on the psychrometric chart mentioned on page 11 in the text. One pound of outside air at 60° F (point *O* on the diagram) is heated to 160° (point *A*); its moisture content in pounds is still unchanged, namely 0.011 pound vapor per pound dry air. It is then cooled as a result of evaporating water in the dehydrater to 120° (point *B*), where it has now a moisture content of 0.020 pound per pound of dry air. It will have a dew point represented by point *C*, somewhat less than 80°. The air is discharged, in this example, at point *B*. It could, of course, be cooled to 87° (point *D*), where it would be saturated, with a moisture content of 0.028 pound per pound of air. Line *AD* shows the humidity and temperature relation as the air is cooled adiabatically in the dehydrater. The wet-bulb tempera- of 87° is determined by the temperature at point *D*, and *AD* would therefore be designated on the chart as the 87° wet-bulb-temperature cooling line. The psychrometric chart has lines nearly parallel to *AD* for every 2-degree change in wet-bulb temperature. If, therefore, we start with air at a different temperature, say 155°, with a wet bulb of 92°, we move vertically from the base line at 155° until the 92° cooling line is reached for a different point *A*.

ratio: $\frac{160-120}{160-60} = 0.4$. Since the dehydration of fruits under these conditions would be prohibitively expensive, normally 50 to 75 per cent of the exhaust air is recirculated, after being reheated to 160° and mixed with the requisite proportion of fresh air. In this way much fuel is saved. Without recirculation, the minimum heat requirement per pound of water evaporated is about 2,700 B. t. u.; with recirculation, this can be reduced to 1,600 or 1,700 B. t. u.

Recirculation is particularly advantageous in dehydrating fruit. Its disadvantages for vegetables are twofold: first, it increases the drying time and thus reduces the output; second, since vegetables must be reduced to much lower moisture contents than fruits, the humidity must be maintained at a lower level. Consequently a 30 per cent relative humidity at 140° F is too high for cabbages and onions, which must be brought to 4 per cent moisture.

Measurement of Relative Humidity.—If one places a wet cloth wick around the bulb of a thermometer, leaves the bulb of a second thermometer uncovered, and hangs both in a stream of dry air, the wet-bulb thermometer will read several degrees lower than the dry-bulb because evaporation of moisture takes heat from the wick and from the thermometer in proportion to the rate of evaporation. A suitable assembly is shown in figure 2. The lower the relative

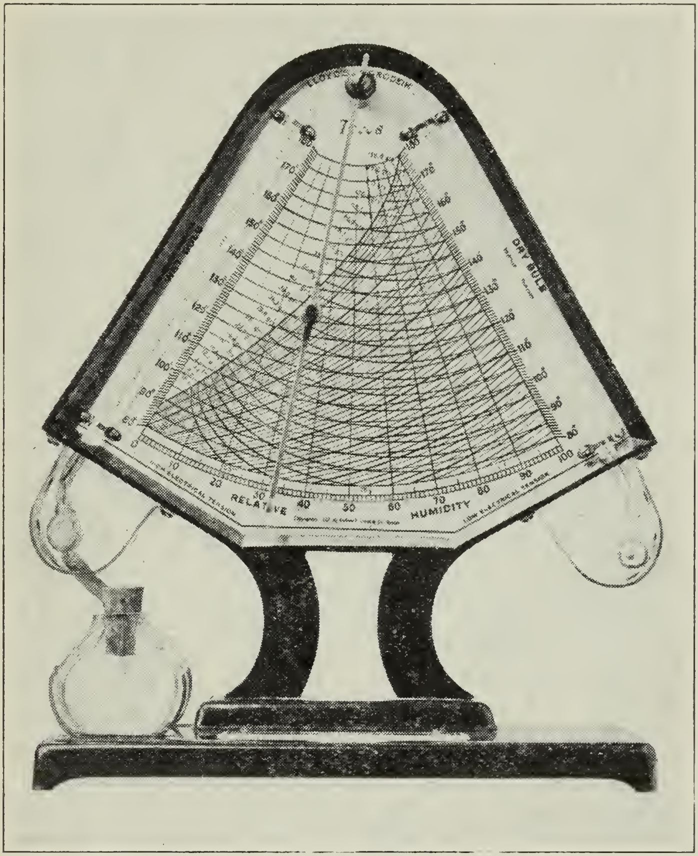

Fig. 2.—Wet-bulb and dry-bulb thermometers with relative humidity chart, for installation in the dehydrater.

humidity of the air, the more this difference increases. Figure 3 gives the relative humidity at different wet- and dry-bulb temperatures. An example will illustrate the use of the figure. Assume a dry-bulb temperature of 150° F and a wet-bulb of 100°; one starts from the base line at 100° for the wet-bulb temperature, and follows the vertical line on the chart, until it cuts the horizontal line for a dry-bulb temperature of 150°. At this point, it is clear that the relative humidity is 18 per cent.

The dehydrater should be equipped with wet- and dry-bulb thermometers placed at the air-entry and air-exit ends of the tunnel and conveniently located behind small glass windows in the tunnel walls.

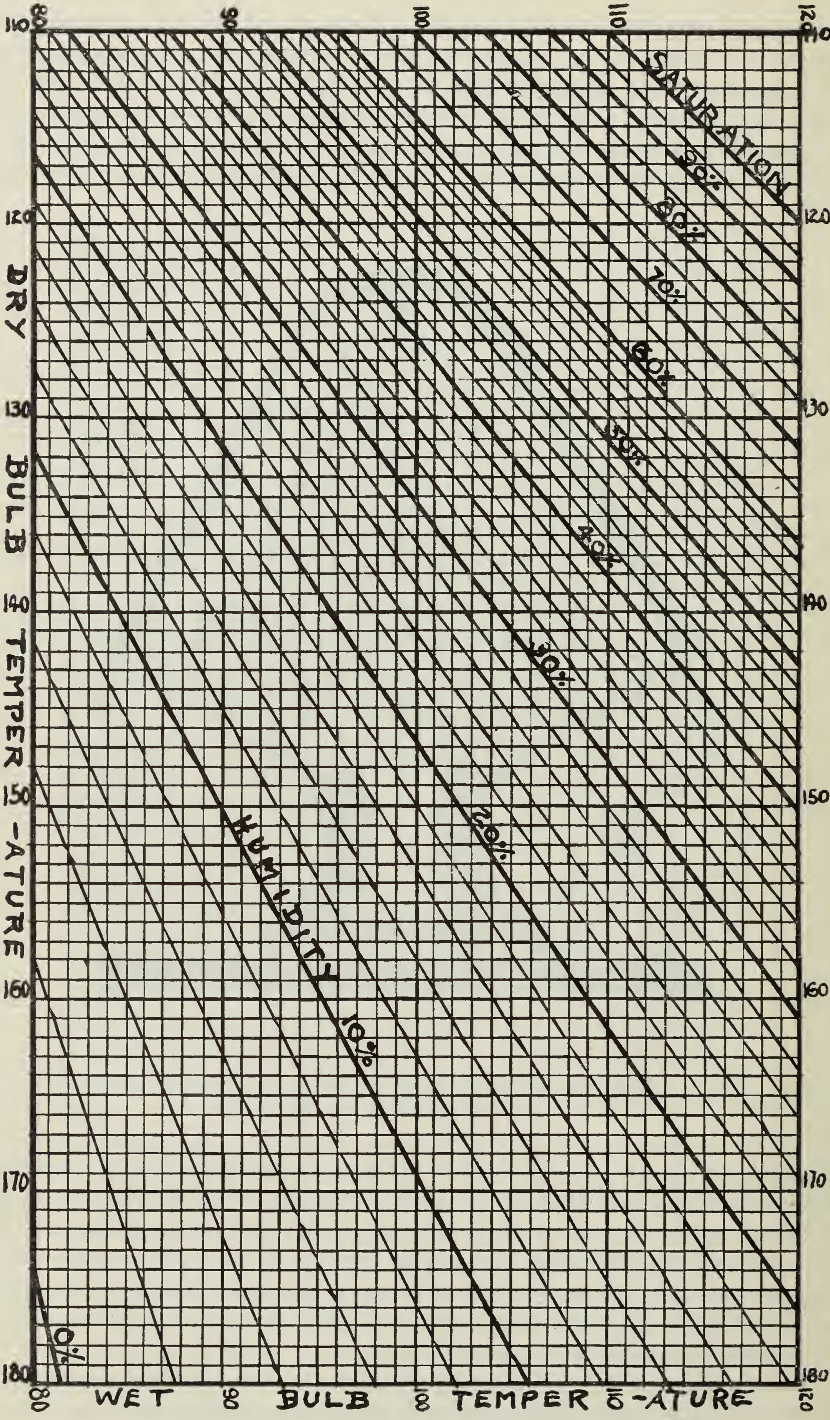

Fig. 3.—Chart for determining relative humidity.
(From Bul. 904.)

Only distilled or rain water should be used to fill the reservoir that moistens the wick on the wet-bulb thermometer.

The reason for this is simple, that tap water contains salts. As the water is evaporated, there would be a steady accumulation of these salts on the wick. This would lessen the rate at which the water is evaporated, and the wet-bulb thermometer would give too high a reading, and the humidities calculated from such values would be in serious error.

TABLE 2

EFFECT OF AIR VELOCITY ON LENGTH OF TIME NEEDED TO DRY CARROTS, CABBAGE, AND PEAS*

Air velocity in linear feet per minute	Time required to dry		
	Carrots	Cabbage	Peas
	hours	*hours*	*hours*
250	5.3	5.5	4.7
500	4.0	4.0	3.3
750	3.5	3.5	2.6
1,000	3.0	3.2	2.0

* Data from Christie and Matsumoto (1925).

TABLE 3

MOISTURE CONTENT OF SEVERAL DRIED VEGETABLES AS AFFECTED BY RELATIVE HUMIDITY AND FINISHING TEMPERATURE OF DEHYDRATION

Vegetable	Moisture content at equilibrium under the stated conditions					
	140° F and 8–10 per cent rel. hum.	140° F and 30 per cent rel. hum.	150° F and 8–10 per cent rel. hum.	150° F and 30 per cent rel. hum.	160° F and 8–10 per cent rel. hum.	160° F and 30 per cent rel. hum.
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Cabbages	1.6	8.0	1.5	5.3	1.9	4.0
Onions	3.0	6.5	2.2	6.0	2.0	5.2
Carrots	2.5	3.8	3.6	3.5	2.5	2.3
Potatoes	2.7	5.0	2.9	4.8	2.7	4.0

Effect of Air Velocity on Drying Rate.—The velocity of the air in a given tunnel determines the volume of air per minute. Other factors being equal, the greater the velocity, the more rapid the rate of drying.

In experiments made by Christie and Matsumoto (1925) the effect of air velocity at 160° F on the length of time required to dry carrots, cabbage, and peas was found to be as shown in table 2.

Doubling the air velocity reduced the drying period materially, but not in half, because the rate of diffusion of moisture to the surface in the nearly dried product becomes an important factor.

Relative Humidity of Air as Related to the Moisture Content of the Dried Product.—For most dehydrated vegetables the Army specifications require a moisture content below 5 per cent; for potatoes below 7 per cent; for cabbage and onions below 4 per cent. These represent a "brittle dry" condition, and the air at the finishing end of the dehydrater must be of low relative humidity.

In recent tests, at the temperatures and relative humidities given in table 3,

cabbages, onions, carrots, and potatoes (after equilibrium was attained) possessed the moisture contents shown in the table. The vegetables had been reduced to less than 5 per cent moisture before the experiment began and were then heated on trays in the dehydrater until fairly constant weights were attained. The heating period was 6 to 8 hours.

Since some decomposition occurs at the higher temperatures and since final equilibrium may not have been reached in all cases, there are several discrepancies in the data; but, on the whole, the values are fairly consistent. As will be seen, at 140° F and 30 per cent relative humidity, cabbages and onions could not meet the requirement of less than 4 per cent moisture, although potatoes dropped below the 7 per cent, and carrots below the 5 per cent maximum moisture contents specified by the Food Distribution Administration (formerly the Agricultural Marketing Administration). Carrots are usually finished at 150° to 160°. As shown in the table, they readily reach less than 5 per cent moisture at 30 per cent relative humidity at these two temperatures. Makower and Dehority (1943) obtained somewhat lower values for 158°, with 10 per cent and 20 per cent relative humidities, by storing samples under these conditions.

Effect of Humidity on Critical Temperature.—Near the end of the drying period any vegetable becomes susceptible to heat damage. In the tests recorded in the preceding table, observations were taken on color, odor, and flavor after 6 to 8 hours' heating. Cabbage showed slight but definite injury at 140° F with 8 to 10 per cent relative humidity, and pronounced injury at 30 per cent. Carrots showed no appreciable injury even at 160° and 30 per cent relative humidity. Potatoes showed slight injury at 160° at a humidity of 8 to 10 per cent, and at 155° and 30 per cent. In commercial practice some potatoes become reddened at 145° and low humidity; and in other experiments marked variability has been observed in resistance of dried potatoes to heat. Onions showed marked injury in color and odor at all temperatures used in this case and both humidities of this experiment.

As previously stated, all vegetables are much less sensitive to heat when of high moisture content; only near the end of the drying period is heat damage apt to occur.

Relative Humidity and Casehardening.—Peas and potatoes may show casehardening—that is, formation of a tough layer at the surface, making it difficult to remove the last moisture from the center of each piece. Sweet potatoes cut in thick pieces may also caseharden, but other vegetables usually do not exhibit this phenomenon to a serious degree. Casehardening is less evident at high than at low relative humidity. In the dehydration of all vegetables, however, very low relative humidity should be used in the final stages of drying; experiments have shown that dehydration is more rapid at low relative humidity even with products that caseharden because of the retarding effect of high humidity.

Effect of Type of Vegetable on Drying Rate.—Shredded cabbage dries rapidly, whereas peas and thick slices of potato dry rather slowly. In a typical experiment blanched cabbage dried in 3 hours at 150° F, peas in 5 hours, string beans in 7 hours, thinly sliced carrots in 3 hours, and corn cut from the cob in 4½ hours.

In drying, carrots curl and separate, whereas blanched potatoes and cabbage tend to clump together; this retards the drying by impeding the air circulation. Peas may caseharden and therefore dry slowly toward the end of the drying period.

Effect of Tray Load on Drying Rate.—The more heavily the tray is loaded, the more slowly will a prepared vegetable dry; but at a very low tray load such as ¼ or ½ pound per square foot, the output per day will usually be less than at a moderate tray load such as 1 to 1¾ pounds per square foot. With

TABLE 4

EFFECT OF TRAY LOAD ON DRYING TIME

Load per square foot, in pounds	Drying time	
	Spinach	Carrots (cubed)
	hours	*hours*
2	11	11
1½	8½	10
1¼	6½	9
1	5½	9
¾	3	8

TABLE 5

EFFECTS OF SIZE AND SHAPE OF PIECES ON DRYING RATE

Form and size of pieces	Drying time	
	Potatoes	Carrots
	hours	*hours*
½	14	9½
¼ inch slices	10½	7
½ inch cubes	7	5
⅜ inch cubes	6	3½
⅛ inch slices	4¾	3¼
Julienne strips	4¼	3

excessively heavy loading of the trays in the usual tunnel dehydrater, however, the daily output is apt to be less and the quality poorer than at moderate loading. For each product there is a "happy medium," best determined by trial.

Table 4 illustrates how the tray load affects the drying time in a small forced-draft dehydrater operated at 148° to 150° F.

As will be noted, the time required to dry spinach was more or less inversely proportional to the tray load. The spinach at the heavier tray loads tended to form slow-drying lumps, whereas at ¾ pound per square foot it dried rapidly and uniformly. In commercial practice similar results have been observed with cabbage, but heavier loads are possible with carrots. In one large commercial dehydrater the tray load of diced carrots is even as high as 1¾ pounds per square foot.

Effect of Size and Shape of Pieces.—Carrots and potatoes were diced in two sizes, about ½ × ½ inches and about ¼ × ¼ inches; also cut in slices in

Julienne strips (defined on page 36) about $\frac{3}{16} \times \frac{3}{16}$ in cross section. All were blanched in like manner in steam, and the drying rates at 145° F determined by weighing the trays at regular intervals. Table 5 summarizes the data.

Rate of Removing Moisture at Different Stages of Dehydration.—While the food undergoing drying is high in moisture content, the rate of moisture loss is high; but at a low moisture content, the rate becomes very slow. This change is illustrated in the graph of typical vegetable-dehydration curves at constant temperature and air velocity (fig. 4).

In the initial stages of drying, the surface of the product is moist, and moisture transfer from the tissues to the surface keeps pace with evaporation from

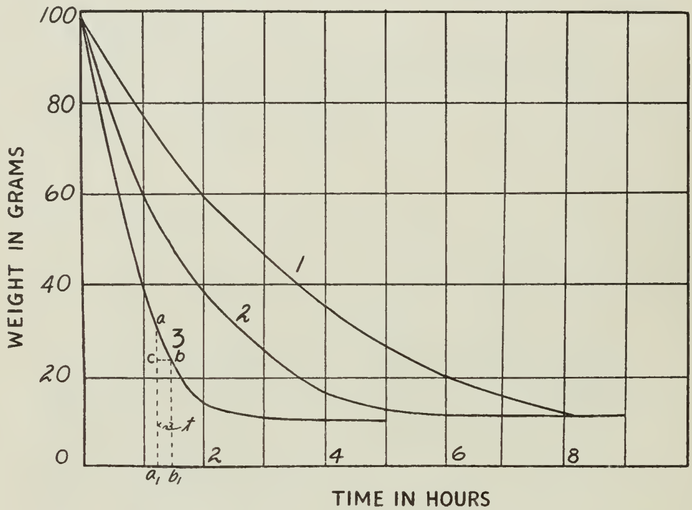

Fig. 4.—Typical drying curves of vegetables dried in a forced-draft cabinet-type laboratory dehydrater at constant temperature. *1*, Unblanched string beans; *2*, blanched string beans; *3*, blanched carrots. See text for explanation of points.

the surface. Near the end of the drying period moisture diffusion is slow, lagging far behind the ability of the hot air to evaporate and remove the moisture.

The rate of drying during any short interval—for example, 10 minutes—can be determined by marking off on the curve a short interval of time, t, as indicated on the graph; erecting the vertical lines $b\ b_1$ and $a\ a_1$, parallel to the weight axis as shown; drawing a line $b\ c$ parallel to the time axis as shown until it meets $a\ a_1$ at c. Then the weight lost, W, in time, t, is equal to $a\ c$.

How moisture content or stage of drying process affects the rate of moisture loss is illustrated by typical data reported by Sugihara and Cruess (1942), who dehydrated blanched string beans at 150° F. In the first 15 minutes the beans lost 45 per cent of their moisture; in the fifth 15 minutes, 6 per cent; in the tenth, only about 1 per cent. In the first 2 hours of another experiment, string beans lost 68 per cent of their weight; in the next 2 hours only 18 per cent; in the third 2 hours only 3.2 per cent. It required an additional 2 hours to remove the next 1 per cent and to bring the final moisture to about 4 per cent.

Because of the extremely low drying rate after about 75 per cent of the

moisture has been removed, the partially dry product is frequently taken from the trays (if it is dry enough not to cake), and the drying completed in bins. (See a later section on bin drying.)

CLASSIFICATION AND GENERAL DESCRIPTION OF DEHYDRATERS

Dehydraters may be classified in several ways: for example, according to air pressure used (atmospheric or vacuum); continuity (as batch, continuous, and progressive); heating method (direct, indirect); source of heat (such as gas, crude oil, coal, or electricity); materials of construction; or nature of the

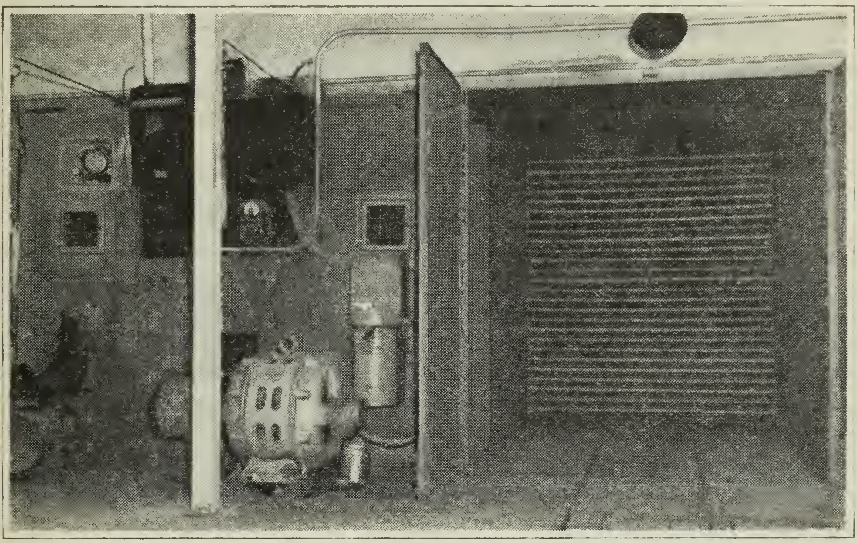

Fig. 5.—Exit end of a tunnel dehydrater, showing a car of stacked trays containing dried carrots. The motor operates a large fan serving two tunnels. (Courtesy of E. A. Couture Co.)

drying compartment and method of supplying the air (such as tunnel, cabinet, stack). Instead of considering these in detail, we shall give most attention to the more important commercial types.

Counter-Current Tunnel and Truck Dehydrater.—Most of the dehydraters used for vegetables in California are of this type. Generally it consists of a tunnel about 6½ feet wide by about 7 feet high in cross section and about 50 to 60 feet long. Cars of trays, the latter usually 6 × 3 feet in size, loaded with the freshly prepared raw product, enter the cooler, moister air at the exhaust end of the tunnel and are moved forward progressively toward the hotter, drier end, where drying is completed.

There is an air-heating device, usually a furnace of firebrick in which natural gas heats the incoming air by mixing air and gases of combustion, or a steel furnace shell with radiating pipes. A large fan circulates the air through the furnace and across the trays. Beside, above, or below the drying tunnel is a second tunnel or large duct, which contains the furnace and fan and through which any desired proportion of the air used in the drying tunnel may be returned to the heating chamber and used again in drying.

Figure 5 shows the principal features of the tunnel-and-truck dehydrater. Customarily one fan, one furnace, and one air-return duct serve two drying tunnels. The cars move on steel rails or, if castor wheels are used, on the concrete floor of the tunnel and preparation room.

The average tunnel holds about 10 tons of prunes or 5 tons of vegetables, since the loading with vegetables is about half that used for prunes. Some operators, however, use only 40 feet or less of the tunnel, in order to secure maximum drying rate.

Parallel-Current Tunnel and Truck Dehydraters.—The parallel-current tunnel is identical in design with the counter-current, the only difference lying in the method of operation. In the parallel-current method the fresh product enters the hot-air end of the tunnel, where the maximum temperature exists; and it then travels progressively toward the cool, moist, exhaust end. Drying is completed in moist, relatively cool air.

During the first hour or two the drying proceeds very rapidly because the product is moist and quickly gives up its moisture, and because the hot air is at or near its maximum drying capacity. As the product approaches the exhaust end the increasing humidity and decreasing temperature markedly retard the drying. In fact, a parallel-current tunnel of the commercial size usually cannot reduce the moisture content below the maximum allowed in Army specifications. For this reason the parallel-current tunnel is generally used only for the first stage of dehydrating vegetables, the second or finishing stage being conducted in a second tunnel or compartment operated on the counter-current principle. (See next section.)

Two-Stage Tunnel Dehydration.—In Canada the two-stage procedure, combining parallel and counter current, has been followed in operating several commercial tunnel dehydraters. It is used in one of two manners:

In one case, two tunnels are used; and two thirds or more of the moisture is removed from the apples or vegetables in a parallel-current tunnel whose initial temperature may be 190° F or higher. The drying is then completed in a second tunnel operated on the counter-current principle, finishing at 135° to 150°.

In the other case, a single tunnel is used; but it is equipped with a movable partition, so placed that the first section of the tunnel is shorter (usually by one half) than the second. The loaded trucks of fresh product enter the first section and travel parallel current. The truck, on reaching the movable partition, is transferred to the second compartment, where its progress is counter current.

Usually two fans and two air heaters are employed. Part of the spent air from both compartments is exhausted from the center of the tunnel, and part of the air is recirculated. This two-stage tunnel is also known as a center-exhaust tunnel dehydrater. Extremely rapid drying occurs in the parallel-current tunnel or section; in the second or counter-current tunnel or section the moisture content can be reduced to the desired point. Over-all drying time is much shorter than in the counter-current tunnel. See figure 6 for the floor plan of a two-stage, center-exhaust dehydrater.

Truckless Forced-Draft Tunnels.—If the tunnel is small in cross section, for example 3 × 4 feet, the use of trucks may not be practicable. The trays can

rest on slides or rollers extending from one end of the tunnel to the other. For ease in moving the trays the tunnel may be sloping, the fresh trays entering the upper end and the dried product being removed from the lower. As in the tunnel that uses trucks, operation may be according to either the counter-current or the parallel-current methods. There should be a return air duct, adequate air-heating capacity, and ample fan capacity.

Forced-Draft Compartment Dehydraters.—In this type, cars of trays or trays on runways enter the dehydrater from the side and remain stationary throughout the drying. Heated air is forced across the trays, usually from the side, or upward through them. This purpose may be accomplished by forcing heated air by fan into a chamber which extends beside the entire length of the dehydrater and from which the air enters the drying chambers through louvres between the trays. By means of a similar chamber on the opposite side, or

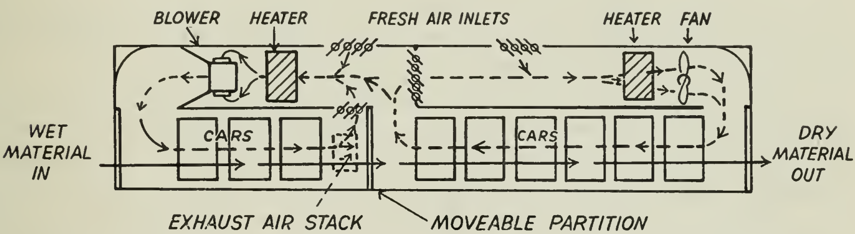

Fig. 6.—Floor plant of a forced-draft, recirculation, center-exhaust, two-stage-tunnel dehydrater. (After W. B. Van Arsdel.)

above the dehydrater, the spent air may be returned to the furnace and fan for recirculation. The direction of flow, in some such dehydraters, can be reversed at regular intervals to secure more uniform drying. The compartment dehydrater is sometimes used as the first stage in two- or three-stage drying. See previous section on two-stage drying.

Forced-Draft Combination Compartment and Tunnel.—In this dehydrater the cars of trays enter at one end of the tunnel, which is usually about 50 feet long; but flexible vertical baffles on the walls separate the trucks from each other and virtually make a compartment for each. The trucks move forward periodically. A large fan and heating unit warm and circulate the air lengthwise of the tunnel; at the same time smaller fans located above the tunnel, one for each truck, circulate the air crosswise of the tunnel and between the trays. Thus the air is moved not only forward but crosswise, the net effect being a spiral forward course. Any desired proportion of the air can be recirculated. Several auxiliary heaters spaced at intervals along the tunnel reheat the air and maintain a nearly maximum temperature throughout the dehydrater; hence the drying rate is rapid. This dehydrater is more complex than either the simple-tunnel or the simple-compartment dehydrater.

Center-Intake End-Exhaust Tunnel.—A considerable number of these dehydraters are being used for prunes and grapes. Air enters via a large pit under the center of the tunnel, flows upward, and then travels toward each end. The cars move counter current through the wet half of the tunnel, parallel current through the dry and hot end. In other words, this type operates

in the opposite manner to the two-stage, center-exhaust tunnel previously described.

The center-intake tunnel is fairly satisfactory for prunes, or for any other product dried to about 15 per cent moisture; but with vegetables, which must be brought to a lower moisture content, it would probably be difficult to attain the desired results in a reasonable time. Since the drying during passage through the first half of the tunnel would be much slower than in the first section of the center-exhaust tunnel dehydrater, deterioration might be appreciable.

Forced-Draft Continuous-Tunnel Dehydrater.—This dehydrater consists of a tunnel through which the product is carried by one or more endless woven-wire or similar metal drapers or belts and is dried in a current of heated air. The air may be forced upward through the conveyor and product, or across them; or it may travel lengthwise of the drying tunnel as in the tunnel and truck dehydrater. Such a drier is serviceable for chemicals, soap chips, starch, and the like. Formerly one was used at Middle River, California, to prepare sulfured sliced unblanched potatoes for potato flour.

Handling costs are low because of the little labor required in loading and unloading; but the drying area is small in comparison with that of a tunnel of like cross section equipped with trays. Also, the length of the drying period is not easily adjusted to suit variation in the condition of the raw material and in the relative humidity of the outside atmosphere. This dehydrater is of doubtful utility for vegetables except, perhaps, as a parallel-current drier in a two- or three-stage unit. In this case the second stage would utilize a counter-current tunnel-and-truck dehydrater or a drying bin.

Natural-Draft Dehydraters.—In these the air beneath the drying compartment is warmed and then, being lighter than the adjacent unheated air, rises through or across trays or a drying floor. The heat carried to the product by the air causes evaporation, and the moisture-laden air escapes from a ventilator.

It is difficult to control the temperature closely in the drying chamber. Furthermore, these driers are inefficient in their use of heat; drying is apt to be slow and uneven. They are usually less costly to build than the forced-draft dehydraters.

A common natural-draft drier is a tower or stack evaporator like the one used in Watsonville, California, for apples. Several trays rest on runways, one over the other, above the furnace and heating pipes. The freshly loaded tray, entering on the topmost runway, is transferred downward periodically each time a tray of the finished product is removed from the lowermost runway.

In the Oregon tunnel, natural-draft drier, the drying compartment slopes and is fitted with long runways extending from one end of the tunnel to the other, each holding several trays. The lower end of the tunnel is directly above the furnace and radiation pipes. This device is used extensively for prunes.

The dry kiln consists of a slatted floor measuring about 20 × 20 feet, above a furnace and radiating pipes. The heated air rises through the sliced product, which is stacked to a depth of about 12 inches on the floor. This kiln is used for apples in New York state and is also used widely in California for hops.

Though the natural-draft driers are inefficient and wasteful of fuel, besides

being high in labor cost, they will serve for vegetables if operated carefully and intelligently. In out-of-the-way localities or frontier regions, where power for a fan is lacking, they could be used to advantage.

Vacuum Dehydraters.—Dehydration in vacuum offers two advantages—namely, low drying temperatures and the absence of air. The disadvantages are the expensive and complex equipment; the difficulty in transmitting heat to the product; the small output per $100 of plant investment; and the danger of scorching in the attempt to hasten drying.

Vacuum driers are of several types. In the shelf drier, the raw material is spread on hollow metal shelves in a steel chamber, which can be sealed and subjected to high vacuum. The heating medium (steam, hot water, or hot oil) is circulated through the hollow shelves; and heat reaches the product through the metal walls of the shelves. Recently infra red rays have been proposed as a source of heat in vacuum driers. In an alternative method, electricity can be used to heat the product through the metal trays resting on resistance-metal grids. There is no appreciable air circulation. The water vapor travels to a water-cooled condenser, where it is condensed and removed by pump, or by barometric water-spray condenser and overflow from a barometric leg.

The vacuum drier is more useful for reducing partially dried fruits and vegetables to a low moisture content than for drying raw materials of high moisture. Several large vacuum driers are used successfully by a factory in Oakland, California, for reducing chopped dried fruits to extremely low moisture.

Continuous-vacuum driers have been built; but mechanical difficulties and other reasons make them unsuitable for fruits or vegetables.

Liquids and purees can be drum-dried under high vacuum. The method is useful for products of this kind, which will not stick to the hot surface and which would be injured seriously by oxidation.

Atmospheric Drum Driers.—The liquid, puree, or slurry is spread on the surface of a steam-heated revolving stainless-steel drum about 8 feet in diameter, 12 to 14 feet in length. The thickness of the film, the degree to which it has previously been concentrated, and the rate of rotation are so adjusted that, by the time the product has rotated to a certain position, the material is dried and is scraped off by a knife extending the length of the drum. The dried food leaves the drum in a continuous sheet, cooled and made friable by a current of dried cold air. Broken into flakes, it is conducted from the drying room by screw conveyor and is then packed at once in airtight containers to prevent moisture uptake with consequent caking. The drier may have one drum, or the liquid may be spread between two.

Drum driers are used successfully for tomato soups, tomato cocktail, and cranberry sauce; for whey, buttermilk, and skim milk dried for stock feed. They should be successful with vegetable purees.

Rotary Driers.—In this type, the material is fed in at one end of a rotating cylinder, revolving about a lengthwise axis. It is automatically conveyed through the cylinder in contact with the drying medium—usually air—which traverses the cylinder either in parallel flow with the product or in countercurrent flow. The heated air may also enter the cylinder throughout its length from openings (louvres) in the inner wall of the double-walled cylinder. In

other heating systems, steam pipes extend lengthwise of the cylinder; or the inner surface of the cylinder is heated by a steam jacket.

As it tumbles the product violently, this drier is not suitable for most vegetables. It is successful with precooked beef, alfalfa hay, apple pomace, grape seeds, and other firm, easily dried materials.

Spray Driers.—In spray drying, the fluid product is atomized under high pressure through a fine nozzle or by a rapidly revolving centrifugal atomizing disk into a violently whirling blast of heated air in a circular chamber. The droplets, drying almost instantaneously, fall to the bottom of the drying chamber, or are floated by air current into dust collectors or bag filters. The resultant powder is packed at once, often in airtight containers.

This drier is in general use for powdered milk and eggs. It is also successful for fruit juices, provided a drying agent such as dextrose, milk sugar, or skim milk is added. It is used commercially for pea soup made from field-dried peas. Vegetable purees other than tomato must be broken up to colloidal-sized particles by a colloid mill or "disintegrator" before spray-drying.

Usually the raw product is concentrated in vacuum to a fairly high density before spray-drying in order that maximum capacity and satisfactory dryness may be attained.

For further discussion of spray, drum, and vacuum driers see Rosseau (1939).

Heat Sources.—In many parts of California natural gas is available for industrial use. Where it is employed, the products of combustion are mixed with the air used in drying, so that most of the heat generated enters the dehydrater. If available, natural gas is an ideal fuel for dehydration: it is inexpensive, clean-burning, high in heat content, and easily regulated.

Many dehydraters also use special fuel oils, such as stove distillate, and special burners that give complete enough combustion to permit the combustion products to be mixed with the air used in drying. Crude oil is apt to burn less completely and to impart off odors and flavors, although used successfully with special burners now available.

Where coal is used as the fuel, the air is heated by flowing over a steel furnace and flues through which the products of combustion pass; or steam is generated, and the air heated by steam radiation. This may be termed an indirect method.

Electricity can be used to heat metallic grids, which in turn heat the air; but, except for experimental use, the cost is excessive.

In drying in vacuum there is direct transfer of heat to the trays of food from hollow steam shelves or pipes, or from electrically heated elements made up of resistance metal.

Relative Heat Efficiency of Several Dehydrater Types.—In Bulletin 330 of this station, Cruess and Christie (1921) measured the fuel consumption and evaporative capacity of several types of fruit dehydraters. Heat efficiency is usually expressed as per cent of the heat value of the fuel actually utilized to evaporate moisture. As previously stated, much heat is unavoidably lost in stack gases, spent air, and the like. During actual dehydration, therefore, it is difficult to attain fuel efficiency above 50 per cent: at least 2,000 B. t. u. of heat per pound of water evaporated must be furnished to the dehydrater.

Natural-draft driers proved much less efficient in the use of heat than forced-draft dehydraters, although the latter also differ considerably in that respect. A ceramic-oven-type dehydrater was efficient in its use of fuel, but its drying rate was extremely slow because of inadequate air flow.

The maximum fuel efficiency, 58 per cent, was attained by a University Farm type tunnel dehydrater using air recirculation. Several other forced-draft tunnel dehydraters showed above 40 per cent fuel efficiency, whereas two natural-draft driers attained only 14 and 24 per cent respectively.

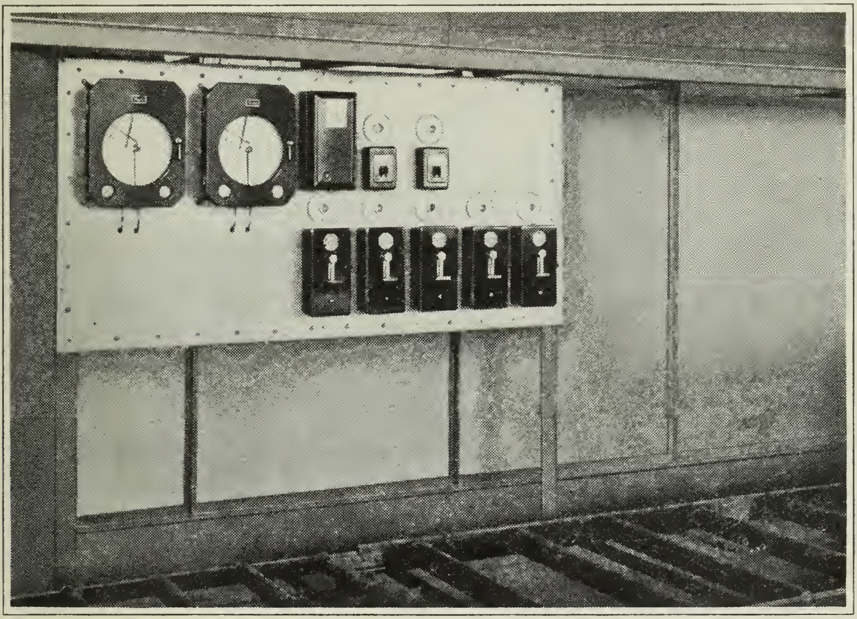

Fig. 7.—Automatic temperature control, and recording instruments, on a dehydrater. (Courtesy of the Taylor Instrument Co.)

Temperature Control and Recording.—The temperature of the ingoing dry air must be closely controlled, because a drop at the wrong time will reduce the output and a rise may cause scorching. In California the outside atmosphere may range from 25° to 60° F (early in the morning) to 50° to 85° or above (at midday) in a typical vegetable-dehydration locality. If, accordingly, automatic temperature control is not used, the operator must adjust the fuel supply to the furnace or otherwise regulate the temperature. On the night shift, conditions are conducive to neglect; quality may be ruined by faulty manual temperature regulation.

The best plan, consequently, is to equip the dehydrater with an automatic temperature control, kept functioning at all times (fig. 7). Controllers are usually operated either by a vapor-tension control bulb placed in the hot end of the tunnel and connected to a control valve in the fuel line or steam supply, or by an electrically operated controller similarly placed and connected. Such devices are serviceable and not unduly costly.

It is also desirable to have a 24-hour record of the temperature for each

day's operations. Often the temperature-control mechanism and recording instrument are in a single assembly. The record consists of a line automatically drawn by a pen on a circular time-and-temperature chart.

Auxiliary Drying Bins.—Toward the end of the dehydration period, vegetables lose their moisture very slowly and are more susceptible to heat injury.

In order, therefore, to increase the output and to control quality and final moisture content more closely, some operators now remove certain vegetables from the dehydrater at the "leathery" stage and place them in bins, through which a current of very dry air of 110° to 125° F is passed until the moisture content reaches the desired low level. The use of finishing bins greatly in-

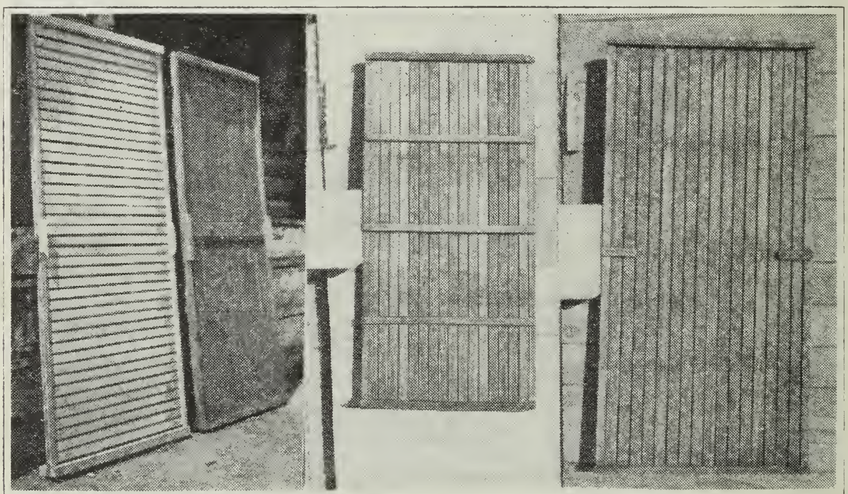

Fig. 8.—Types of 6 × 3 foot wooden trays: At the left is shown a tray with crosswise slats, and one with solid bottom. The two at the right are top and bottom of a tray built of lengthwise slats; the bottom side has the cross cleats.

creases the output, permits closer control of final moisture content, and reduces danger of heat injury.

In moist weather the air may have to be dried artificially, as by silica gel, calcium chloride, or refrigeration. Normally, however, the drying rate is adequate at 120° to 125° F without such treatment. The bin can be made rectangular, with wooden walls. Its screen bottom is connected to the hot-air duct.

Trays.—Since most tunnel dehydraters used for fruits in California are equipped with slat-bottom wooden trays measuring 6 × 3 feet and with trucks designed for this size of tray, those using fruit dehydraters for vegetables have adopted the 6 × 3 slat tray. The trays on the trucks rest crosswise of the tunnel. As a rule, new trays must be built, because bits of imbedded fruit stain the vegetables.

The usual wooden tray (fig. 8) is made up of the following pieces: for the bottom, 20 to 23 pieces $1\frac{3}{8} \times \frac{3}{8}$ inches × 6 feet; each end of 1 piece, $1\frac{3}{8} \times 1\frac{7}{8}$ inches × 3 feet and 1 piece $1\frac{1}{4} \times 1\frac{1}{8}$ inches × 3 feet; each side of 1 piece $1\frac{1}{4} \times \frac{1}{2}$ inches × 6 feet; and for center cross strips, one piece $1\frac{1}{4} \times 1\frac{7}{8}$ inches × 3 feet.

The ends are higher than the sides, giving a space between trays of about 2 inches, permitting the air to flow across the shorter (3-foot) diameter of the trays. Lengthwise flow has been found to result in very uneven drying. The wood used should not be resinous or pitchy, nor impart disagreeable flavors, nor stain the vegetables. The preference is for Oregon pine (Douglas-fir).

Galvanized screen can replace wood for nonacid vegetables such as cabbages, carrots, corn, onions, and potatoes; but not for acid ones (tomatoes and rhubarb), which dissolve the zinc and thus become toxic and unpalatable. Screen attached to a galvanized steel frame forms the tray used in some plants.

With continued use, 6 × 3 foot trays will sag near the middle, causing "bunching" of the product and uneven air distribution, with resultant uneven drying. The center of the tray, therefore, should be reinforced with a suitable cross strip; and the bottom center cross strip of one tray should rest upon the top cross strip of the next.

The vegetables now being dried for the Army (potatoes, sweet potatoes, onions, cabbages, carrots, rutabagas, and beets) do not stick badly to the trays; but juicy vegetables such as sliced tomatoes and heavily blanched squash may adhere when dry. To minimize sticking, coat the trays with tasteless, neutral, white mineral oil (confectioner's slab oil), or loosen the vegetables when they have become about two-thirds dry.

VARIETIES OF VEGETABLES FOR DEHYDRATION[6]

Different varieties of some vegetables show considerable differences in their suitability for dehydration. Some information has been secured by coöperative investigations of the Truck Crops, Home Economics, and Fruit Products divisions of the College of Agriculture and also by the U. S. Department of Agriculture; but our present knowledge of this subject is incomplete—a fact to keep in mind when reading the following section.

Desirable Properties.—A suitable variety should be of tender, uniform texture, attractive appearance, and good nutritive value; should not suffer undue changes in quality during dehydration; and should give a profitable yield. These attributes are, as a rule, markedly affected by the climate and by other factors. In figure 9, differences in appearance are plainly visible.

One is apt to find suitable varieties among those already grown in a given locality. The importation of new varieties may result in disappointment.

Beets.—Beets for drying should be globular or top-shaped, deep red, and relatively free from zoning (white bands in the flesh). The Detroit Dark Red is a common globular variety, satisfactory for drying. The Morse Detroit Canner and Ohio Canner are also favorably reported for the eastern United States. Small, flat varieties are apt to be pale. Both they and long-rooted kinds are more costly to dig and top in the field and to handle in the plant.

Cabbages.—Comparison of cabbage varieties requires further study. In the tests the Savoy, a green-leafed, open-head cabbage, gave a better dried product than the several white and the red solid-head varieties compared with it. It is favored by the Army and also the British purchasing agencies. Because,

[6] Drs. J. E. Knott and G. C. Hanna of the Truck Crops Division of the University, and Dr. G. W. Scott of the Associated Seed Growers of Milpitas, furnished many of the variety samples used in the experiments.

however, it is a light producer, growers prefer the solid-head varieties. Golden Acre and Copenhagen Market are, according to Knott (1942), satisfactory commercial early varieties. Also common in California are Danish Ball Head and Winningstadt. The Flat Dutch has not proved very satisfactory, owing to its tendency to darken during drying.

Since cabbage requires a cool climate, it is a late fall and winter crop in many sections, as in the San Joaquin, Imperial, and Sacramento valleys. It can be grown as a summer crop in cool coastal regions. In a recent comparison of several varieties for dehydration, the Copenhagen Market dried products sur-

Fig. 9.—Appearance of string beans when dehydrated (lower row) and when rehydrated (upper row). The varieties are as follows: 1, U. S. No. 5 Refugee; 2, Stringless Green Pod; 3, Kentucky Wonder; 4, Blue Lake. Note that 3 and 4 do not rehydrate so well as 1 and 2.

passed in flavor and appearance the Ball Head, a red variety, and a large flat-headed white variety. Some varieties develop a stale odor and flavor in drying, and others become yellowish.

Carrots.—In a comparison of ten carrot varieties grown at Davis, California, and picked at sacking size, the Imperator, Red Core Chantenay, Danvers Half Long, Morse Bunching, and Nantes gave very good results, the first two being preferred over the others. The color of most other varieties was too light at the core, or less intense than the Imperator and Chantenay. Commercially, Imperator and Chantenay are about equally regarded. The former is given a slight preference by one or two dehydrators in California because it is less apt to have an excessive amount of green tissue near the crown; but Army specifications favor the Chantenay. All varieties left too long in the soil, or over winter, may split, become coarse and woody, develop side roots, and be pale. The optimum time of harvest should not be deviated from greatly.

At present the Chantenay and Imperator are the most important varieties for dehydration in California. The former has shown somewhat higher carotene content in the tests of summer plantings—namely, 0.091 per cent, as compared with 0.067 per cent for Imperator. The Danvers and Morse Bunching averaged 0.067 and 0.066 respectively. In tests of the winter planting, however, Chantenay has not maintained its superiority. Usually, after drying, it shows a somewhat deeper orange color than the Imperator, especially at the core. The average drying ratios for the three pickings, that is for the prepared fresh compared with the dry, were as follows: Chantenay, 9.2:1; Imperator, 7.8:1; Danvers, 8.5:1; and Morse Bunching, 7.4:1.

The Chantenay in the three pickings gave a considerably poorer drying ratio than the others. On November 6, 1942, Chantenay carrots from a local commission market gave a drying ratio of 9.6:1; on November 15, 9:1. For Imperator carrots from Davis on November 13, 1942, the figure was 6.6:1. Apparently, therefore, the Imperator gives a higher yield than the Chantenay of dried product per unit of prepared fresh. The Chantenay often develops a green crown and core, objectionable because the green turns brown on drying. In flavor the Chantenay (after drying, refreshing, and cooking) was in most tests rated slightly superior to the Imperator, but not invariably.

Corn.—A white Country Gentleman strain, a Golden Bantam Cross hybrid, and the open-pollinated Golden Bantam strains of sweet corn were dried. The Golden Bantam types were preferred, being more attractive in appearance and higher in pigment content. The drying ratios were practically identical, the average being about 3.0:1. This, of course, varies greatly with the maturity. The hybrid Golden Cross strains of sweet corn are much the most popular in the East and Middle West. They bear larger ears and heavier crops than the old, open-pollinated Golden Bantam and appear to be equally good in general quality. In some Eastern states, the Country Gentleman and Stowell Evergreen hybrid varieties of white sweet corn are important.

Since the Middle West and the East grow most of the nation's sweet corn for canning and freezing, any large-scale dehydration of this crop will probably occur there rather than here.

Lima Beans.—Only two lots of green lima beans were compared. These, from the Berkeley markets, were a Baby lima and a large lima. The former was preferred in cooking tests on the dried product.

Onions.—Onion varieties vary materially in yield per acre, drying ratio, sugar content, pungency, and color. Pungent varieties of light color are preferred by the Army. Though comparative data are not extensive, there is sufficient information to place several varieties above certain others. As with other vegetables in wartime, dehydrators and the Army must use varieties that are commercially available, even if they are not the best for dehydration. Jones and Bisson (1934) give the following data on the per cent of dry matter of eight well-known varieties of onions grown at Davis:

Variety	Per cent dry matter
Sweet Spanish	5.50
Grano	7.16
Italian Red	8.83
California Early Red	9.68

Variety	Per cent dry matter
Southport White Globe	10.78
Ebenezer	11.17
White Portugal	11.24
Australian Brown	12.10

The Ebenezer, White Portugal, and Australian Brown had more than twice as much dry matter as the Sweet Spanish.

During recent experiments in coöperation with the Truck Crops Division, the following drying ratios were observed for several varieties of onions: Stockton Yellow Globe, ranging from 10.5 :1 to 11.5 :1; California Early Red, 9.5 :1 to 10.6 :1; Grano, 10.9 :1 to 11.7 :1; San Joaquin, 13.6 :1 to 13.7 :1; Southport White Globe, 8.4 :1; and Australian Brown, 7.1 :1 to 6.9 :1. Commercial-scale comparisons on lots of several carloads each at Cashmere, Washington, yielded the following drying ratios, calculated from the prepared fresh[7]: Bermuda (from Texas), 11 :1 to 12.9 :1; Babosa (from Texas), 14.1 :1 to 19.5 :1. Neither variety gave a very light-colored product; considerable yellowing occurred in drying; and the flavor was mild in both cases.

Of the pungent onions, the Ebenezer is among the best for dehydration, though less common in California than some other varieties of lower pungency such as the Southport White Globe and Bermuda. The White Creole, another very hot variety of good drying quality, is at present scarce in California, being found primarily in the Southern States. The Australian Brown, rated as a hot variety, is commercially available. In all the tests (five different lots) it gave a very good dried product, with none of the bitterness mentioned by some investigators. Commercial operators report it as more difficult to peel than some others. The Southport White Globe, important in this state, is excellent for dehydration. Its pungency is relatively high, and it keeps well in storage while fresh. The dried product is white and has good flavor. It is among the best commercial onions. The Italian Red and California Early Red gave dried products of pleasing taste, but their drying ratios were poor. The Army prefers white varieties. The Crystal White Wax, Grano, and Bermuda are, according to Knott (1942), early varieties of mild flavor (not hot) and of low dry-matter content. All things considered, the Southport White Globe is probably one of the best California onions available in quantity. Also, except for the difficulty in peeling, the Australian Brown appears very desirable.

Potatoes.—In dehydration tests, coöperative with the Truck Crops Division, on ten varieties of potatoes, the Netted Gem (also known as Klamath Russet, Idaho Russet, Oregon Gem, and Russet Burbank) was rated highest in quality after drying. White Rose was placed second. Both gave dried products of light color and good cooking quality. Considerably less desirable in color and flavor were the other varieties compared—namely, Houma, Sebago, Chippewa, Sequoia, Bliss Triumph, the 46,000, and the 46,952, the last two being experimental selections. Dehydrater operators in this state prefer Netted Gem to other commercially available varieties. It is of higher starch content than White Rose and gave a lower drying ratio, a greater yield of dry product (about 4.5 :1 compared with about 5.2 :1) in the tests. The other

[7] Data by Paul Mariani, by correspondence.

varieties also gave higher drying ratios than Netted Gem and in general developed a stale flavor in storage. Most of the potatoes of Kern County and the Delta areas are White Rose, whereas Netted Gem predominates in the Klamath and Tule Lake areas and in Idaho. Whether the low esteem in which potatoes from the Delta are held by dehydrater operators is due entirely to the effects of soil and climate, or in part to the variety, is not known. Probably both factors are concerned.

Irish Cobbler is the most important potato of the United States as a whole, and Triumph is second. The former constitutes about 30 per cent of the total acreage; the latter about 15. Katahdin comes third (with about 10 per cent of the total acreage); Netted Gem, fourth (above 9); and Green Mountain, fifth (also above 9). These five varieties represent nearly 75 per cent of this country's plantings. Though important in California, where it constitutes about 80 per cent of the state's potato acreage, White Rose comprises only about 2½ per cent of the total for the United States. No data are available on the suitability of Cobbler and Katahdin for dehydration; the California-grown Triumph was decidedly less desirable than Netted Gem and White Rose.

Sweet Potatoes.—No comparisons of sweet-potato varieties for dehydration were made, beyond drying samples of the Jersey (dry type) and the Porto Rico (moist type, sometimes misnamed yam), from the Berkeley stores. The Porto Rico type was preferred after drying, refreshing, and cooking. The drying ratios were, for the Porto Rico type, 4:1; for the Jersey type, 3.9:1. Both were palatable when dried and cooked.

Caldwell, Moon, and Culpepper (1938), reporting on the relative suitability of forty sweet potato varieties, as grown in the Southeast, considered Nancy Hall, Myers Early, Mullihan, and Mameyita somewhat superior to the others for drying.

String Beans.—Eleven varieties of string beans, grown by the Associated Seed Growers at Milpitas, California, were picked on the same day and dehydrated. Then the cooking quality after drying was compared. The various drying ratios, ranging from 12.8:1 (for Blue Lake) to 5.6:1 (for S. A. No. 1), were as follows: Stringless Green Pod, 6.8:1; Stringless, 9.2:1; Plentiful, 6.7:1; Refugee U. S. No. 5, 8.0:1; Blue Lake, 12.8:1; Stringless Blue Lake, 10.2:1; White Kentucky Wonder No. 9, 10.5:1; White Kentucky Wonder, 8.3:1; Brown Kentucky Wonder, 10.0:1; McCaslin, 10.2:1; and S. A. No. 1, 5.6:1. Although the attempt was made to pick only tender beans of good market quality, there were probably differences in maturity between varieties. Most of the tasters preferred bush to pole beans in general quality after dehydrating, refreshing, and cooking, largely because the pole beans remained wrinkled on cooking, whereas the bush beans became plump, as shown in figure 8. The Stringless Green Pod was rated most desirable of the eleven varieties for drying. Kentucky Wonder gives larger, coarser pods than Blue Lake. S. A. No. 1 refreshed and cooked well. It possesses large flat pods and resembles Scarlet Runner in appearance and taste. For the average consumer its flavor is rather strong.

In the light of present knowledge the authors would recommend the Stringless Green Pod, which, incidentally, is about the most important variety

now grown in the East and the Middle West for canning. Refugee U. S. No. 5 is also very important and, in the tests, gave a very satisfactory dried product. Since much less labor is required in growing and picking the bush varieties, such as these two, growers would probably prefer them to the pole varieties for dehydration in wartime.

Summer Squash.—On several occasions a scalloped white variety of summer squash and some Zuchini summer squash, grown near Danville, California, were compared. Both dehydrated well, and the products when refreshed and cooked were satisfactory. One lot of Crookneck was dehydrated in comparison with Zuchini and Scallop. On refreshing and cooking, its color and flavor were less satisfactory than those of the other two. The drying ratios were as follows: Zuchini, 17.1 :1; Scallop, 10.7 :1; Crookneck, 12.79 :1. While not extensive, the tests indicate that these three popular squashes can be dehydrated satisfactorily.

Squash and Pumpkin for Pies.—At one time (1920-1925) the Boston Marrow squash and the Connecticut Field pumpkin were used in California for dehydration, the products being ground and mixed for pie making. Probably other good pie-pumpkin varieties could also be used successfully.

Tomatoes.—Few varietal comparisons were made with tomatoes. The Santa Clara is the "beefsteak" canning type most commonly grown in northern and central California. Because of its large size, smooth skin, and solid flesh it is easily prepared and loses much less juice on the trays than such juicy varieties as Stone, Norton, Earliana, and Globe. For drum-drying of the concentrated puree for tomato powder, the Stone is used successfully in New York, the Santa Clara and San Marzano in California. San Marzano is the small, pear-shaped tomato popular here for paste manufacture. When cut in half lengthwise and dried unpeeled with the cut surface upward, or when dried whole after peeling, it gave good results. At present drum-drying of concentrated puree is the only procedure in commercial use on a large scale.

PREPARATION OF VEGETABLES FOR DRYING

In California the principal operations in the preparation of vegetables for drying are (1) washing; (2) sorting; (3) trimming; (4) peeling (roots and tubers only); (5) subdividing; (6) blanching; and (7) loading trays. In England and Canada, potatoes and cabbage are often sulfured or sulfited; but at present this step is omitted in California.

Washing.—Root vegetables, tubers, leafy vegetables, tomatoes, and string beans should be thoroughly washed before peeling or blanching, for they usually carry earth, sand, or dust. Unless soiled in preparation, peas, cabbages, and Brussels sprouts ordinarily do not require washing before blanching.

For most vegetables the vigorous agitation and scrubbing given by a rotary washer (fig. 10) is best. This washer, commonly used to prepare tomatoes for canning, consists of a revolving, perforated, galvanized sheet-metal drum, throughout the length of which are spray nozzles located near the central axis. Water under heavy pressure and in ample volume is required. Rotation of the washer rubs the vegetables against each other, loosening the adhering soil.

Spinach and other greens are usually first passed through a long shallow tank of slowly moving water, agitated by compressed air. Sand and small

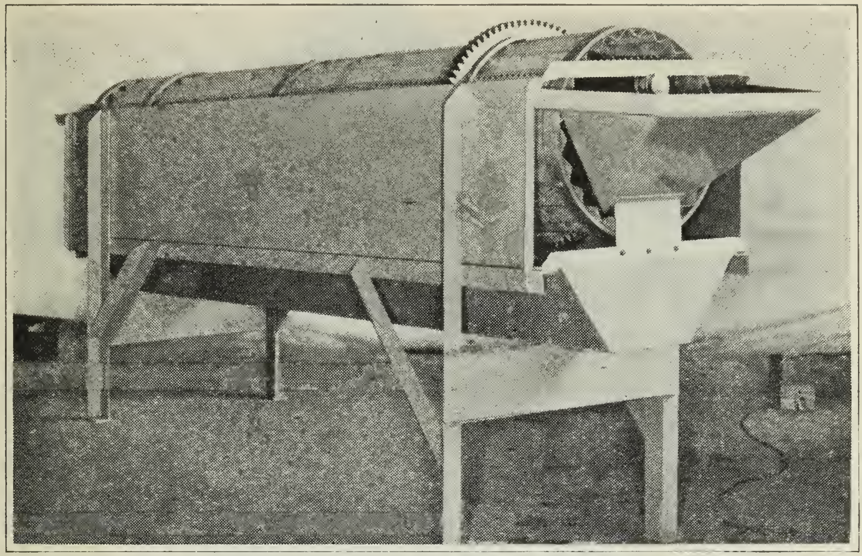

Fig. 10.—A corrugated rotary drum washer. (Courtesy of the Food Machinery Corporation.)

insects are loosened and more easily removed during subsequent more vigorous washing.

Unless potatoes and carrots are thoroughly cleansed before lye-peeling, sand and mud accumulate in the peeling tank and interfere seriously with heat transfer and operation.

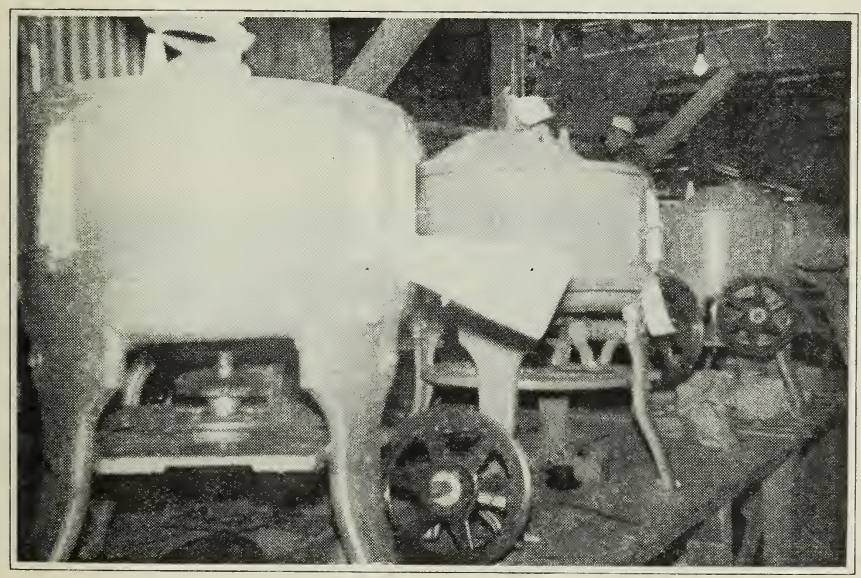

Fig. 11.—A battery of abrasion peelers for potatoes and root vegetables. (Courtesy of H. C. Hensley, Farm Credit Administration.)

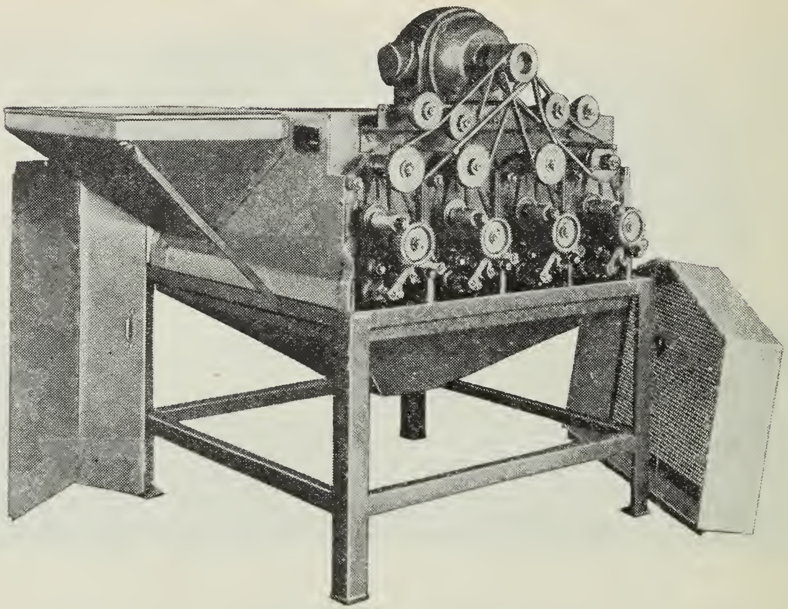

Fig. 12.—A continuous peeler for potatoes, onions, and root vegetables. (Courtesy of the Food Machinery Corporation.)

Rinsing after the lye-peeling or flame-peeling of carrots and potatoes is done in a rotating drum spray washer.

Peeling and Trimming.—Root vegetables and tubers must be peeled before dehydration. Three methods are in commercial use: (1) abrasion, (2) immersion in boiling lye solution, and (3) flame-peeling. Peelers are shown in figures 11, 12, and 13.

The "batch" abrasion peeler is an upright, metal cylinder. The inner surfaces of the walls and bottom are covered with coarse carborundum crystals or similar abrasive material, tightly cemented to the metal. The bottom is

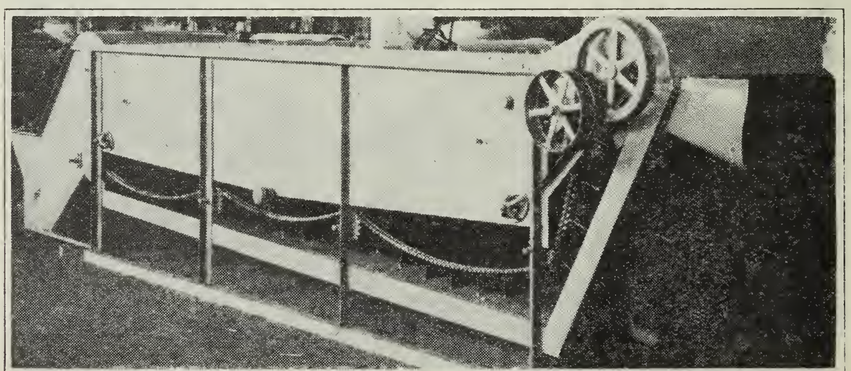

Fig. 13.—A draper-type lye-peeler. (Courtesy of the Food Machinery Corporation.)

rotated rapidly. The skins are rasped off. Sprays of water wash away the gratings of peel and adhering flesh. When the operator judges that peeling is completed, the vegetables are removed through a side door. The gratings from potatoes contain much starch and can be used for stock feed; or they can be ground, and the starch recovered and purified by settling and washing. Loss in abrasion peeling is much higher than with lye- or flame-peeling. For potatoes the loss usually exceeds 25 per cent. The continuous peeler consists of parallel rapidly revolving, abrasive-coated, metal cylinders (fig. 12).

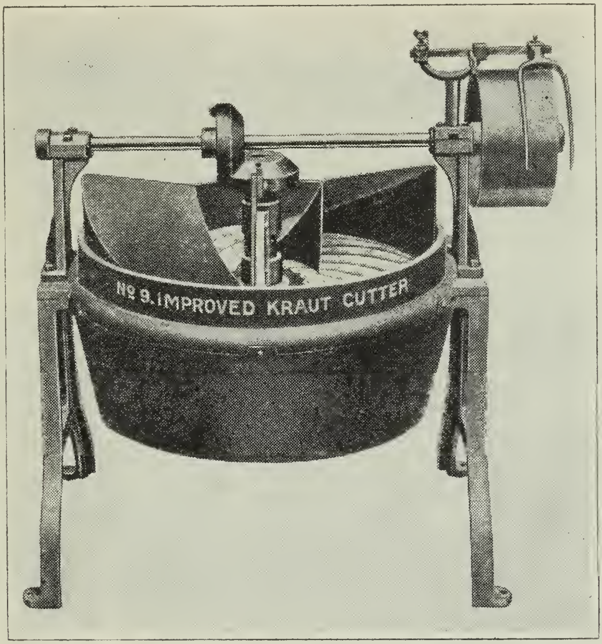

Fig. 14.—A sauerkraut cutter for shredding cabbage. (Courtesy of the Food Machinery Corporation.)

The eyes, adhering patches of skin, blemishes, bruised tissue, and other unfit material are trimmed out by hand as the peeled potatoes travel on a sorting belt. The crowns and roots of carrots are cut off, in addition to trimming.

Potatoes, carrots, beets, sweet potatoes, and parsnips can be peeled in boiling lye (sodium hydroxide) solution in equipment used by canneries for peeling peaches. For carrots about 3 per cent sodium hydroxide is satisfactory; for potatoes and sweet potatoes 10 to 15 per cent, the higher concentration being preferred at present. The peeling operation consists in mechanically agitating in and conveying the vegetables through a tank of boiling lye solution, or in spraying them on a metal door-matting conveyor with boiling lye. In either case, the next step is to wash the loosened and disintegrated peel and lye from the vegetable with forceful sprays of water. The drum spray washer is recommended because it rubs and washes energetically. To check darkening, the lye-peeled potatoes may be wet with dilute salt solution or dilute (½ per cent) citric or hydrochloric acid solution. After the shredding, a rinse removes the acid.

In the flame peeler the vegetables first pass through a rotating firebrick furnace filled with a searing gas flame that chars the skins thoroughly; then through a rotary spray washer that removes and washes away the charred skins. Such a device has been employed in the East for several years to peel potatoes for use in meat products, and in Canada to peel potatoes and carrots for dehydration.

Beets are abrasion-peeled or steamed about 30 minutes, or heated at about 240° F under steam pressure for a shorter time, with roots and trimmed tops in place. They are then cooled and trimmed, and the skins slipped off.

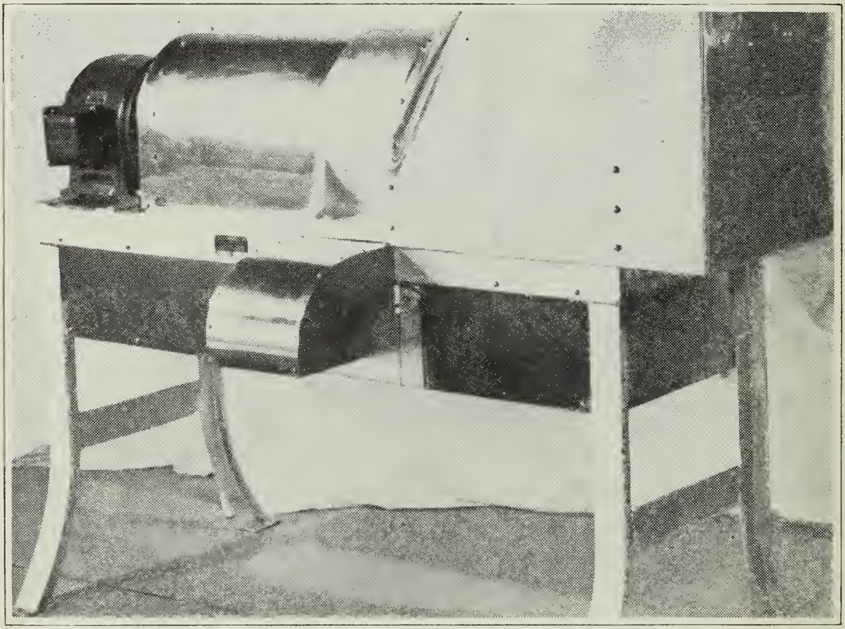

Fig. 15.—Urschel dicing and strip-cutting machine. (Courtesy of the Food Machinery Corporation.)

Subdividing.—To facilitate drying and to make a product of distinctive appearance, onions and cabbage are sliced or shredded (fig. 14); tubers and root vegetables are usually cubed (fig. 15), or cut in strips ("shoestrings" or "Julienne strips"). Potatoes also are riced; that is, after being peeled and cooked in steam, they are formed into spaghettilike strings by extrusion through small holes in a metal plate or screen. Other vegetables may be riced if not too juicy.

Cabbages are sliced in a kraut cutter. The shreds fall upon the tray beneath the slicer, or upon a conveyor.

Onions require a rugged, sharp-cutting slicer, such as a gang of rotating circular knives set on a horizontal shaft, or revolving scimiter-shaped blades of special design. In a kraut slicer the outer paper skins are apt soon to clog the knives.

The Urschel slicer is generally used for dicing and for cutting the root

vegetables and tubers into Julienne strips. The machine employed by fruit canners for cubing pears and peaches for canned fruit cocktail is also suitable, or the Sterling dicer.

Blanching.—For most vegetables, blanching is the chief step in preparation for drying. It is a scalding or precooking in steam or in boiling water. A steam blancher is shown in figure 16. The purpose is twofold: first, to inactivate or destroy the natural enzymes responsible for undesirable changes in color, odor, and texture and for loss of vitamins; second, to facilitate quick refreshing and cooking of the dried vegetables. The effect of blanching on vegetables has been discussed recently by Sugihara, Tsu, and Cruess (1941).

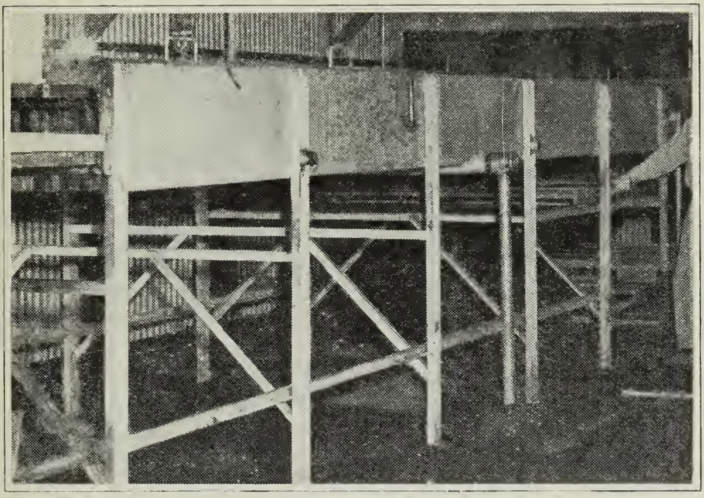

Fig. 16.—A steam blancher. (Courtesy of the E. A. Couture Co.)

In the early days of dehydration, blanching was omitted. Consequently, the dried products were tough, oxidized in color, and haylike or worse in odor and flavor. Even on prolonged cooking they remained tough or fibrous. Blanching is necessary for most vegetables. The exceptions are garlic, onions, and peppers; in these the flavor is more pronounced in the unblanched product.

Blanching in hot water is less desirable than blanching in steam because the water dissolves much of the vitamins, minerals, sugars, and other food substances. Magoon and Culpepper (1924), for example, found that 1½ to 30 per cent of the water-soluble food constituents were lost in blanching in water. The extent of the loss was affected by the variety of vegetable, being low for peas and very high for spinach.

Adam and Horner (1941), at the Campden Experiment Station in England, found that 7 to 56 per cent of vitamin C was lost in blanching of vegetables in water and 16 to 39 per cent in steam blanching. Losses of minerals ranged from 9 to 44 per cent in water blanching, 5 to 20 per cent in steam. Losses, naturally, were heavier from vegetables cut in small pieces than from those cut large or left whole. The loss in steaming results from leaching by the water of condensation.

Blanching in soda solution is highly objectionable: it not only dissolves out valuable nutrients, but hastens the destruction of vitamins B_1 and C.

The British favor blanching successive lots in the same water until an appreciable concentration of water-soluble materials is attained.

The vegetables may be steamed on the trays in a cabinet; but this method may be extremely unreliable. Heating is apt to be slow and nonuniform. In one plant, cabbage on trays placed on trucks was steamed regularly about 6 minutes in a cabinet, and practically none of it reached 100° F. A steam cabinet, if used, must provide ample space between trays and a superabundance of steam. Trays of vegetables may be passed on a conveyor through a long steam box. This method is used for cabbage. After blanching, the cabbage may be cooled by an air blast to prevent overcooking, with resultant poor color and texture.

In the most common method of steam blanching, the prepared vegetables are placed in a relatively shallow layer on a woven wire conveyor and pass continuously through a steam box. Mechanically or by hand, they are then spread evenly on trays.

In some plants, especially in the East, the vegetables are steamed in baskets in cannery retorts under about 10 pounds' steam pressure at about 240° F for about 10 minutes. This method is effective and gives a product which, after drying, refreshes and cooks quickly. It deepens the apparent color of carrots. It involves, however, considerably more labor than does blanching in live steam.

In hot water the blanching may be continuous, as in the usual cannery blancher; or intermittent, as in the blanching of asparagus in baskets for canning.

Loading the Trays.—For uniform and rapid drying, the prepared vegetables must be spread evenly on the trays and not too deep. The load per square foot is much less than for fruits because the pieces are smaller and are more inclined to clump together. About 1 to 1¼ pounds per square foot is the usual tray load, although 2 pounds per square foot or more is used in some plants. Part of an assembly line is illustrated in figure 17.

In some plants the empty trays travel on rollers to the cabbage or onion slicer to facilitate handling. In one plant the car rests on a hydraulic lift and, as the loaded trays are placed upon it, settles into a rectangular pit extending several feet below the floor. The workmen, therefore, need raise the trays only a few inches in loading the truck, whereas usually, in other plants, they must raise the last several trays to a height above their heads (to 6 or 7 feet).

Enzymes and Testing for Adequate Blanching.—As previously stated, blanching has for one major object the destruction of the enzymes that may cause undesirable changes in flavor, texture, color, and odor. Some of these enzymes are oxidative in character. Usually the oxidative enzyme system is assumed to consist of three components: (1) a peroxidase or phenolase that causes oxygen in peroxide form to combine with (2) a second component such as protocatechuic acid to form a dark compound; (3) an enzyme that combines oxygen of the air with catechol or similar compound to form peroxides. The peroxides can be used by the peroxidase to cause oxidation of a susceptible substance.

Several common colorless organic compounds are converted into colored substances by peroxidase-induced oxidation in the presence of a peroxide. Also, any blanching severe enough to destroy peroxidase will destroy other enzymes as well. Peroxidase is probably only one of several enzymes involved in the enzymic deterioration of vegetables during and after dehydration.

In testing the blanched vegetable, a few pieces taken at random from the tray or blancher are broken or cut into small pieces, and 4 or 5 grams of these are placed in a test tube. Water, about 6 to 8 cubic centimeters, is added to

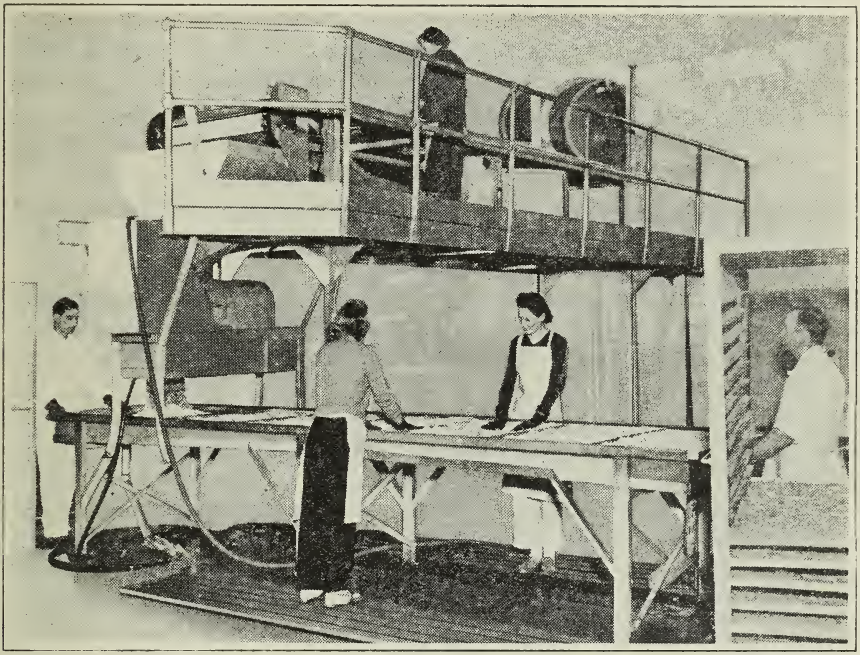

Fig. 17.—Upper right, a rotary washer. Upper center, sorting. Lower left, a cutting machine. Lower center, spreading on trays. Lower right, car and loaded trays. (Courtesy of the Anabolic Food Products, Inc.)

cover. Then 4 or 5 drops of a freshly prepared 0.3 to 0.5 per cent hydrogen peroxide solution and a similar amount of 0.5 to 1.0 per cent pure guaiacol solution in 50 per cent ethyl (grain) alcohol are added. The tube, having been shaken, is allowed to stand 15 to 30 minutes. If the solution and the vegetable, or the vegetable only, develops a marked brick-red color in 15 minutes, the test is considered strongly positive; if only a few faint spots or strips of color appear on the vegetable at 30 minutes, faintly positive. If no color develops in this time, the test is negative. Guaiacol is not satisfactory with carrots, because of their orange color.

Benzidine, another generally used indicator, is less reliable than guaiacol and may occasionally give a positive test even after all the peroxidase has been destroyed by heat. It is useful, however, with carrots. Pyrogallol, hydroquinone, catechol, gum guaiac, protocatechuic acid, alpha naphthol, and many other substances have been used; but some do not keep well in solution. some

give rise to only faint color, and some give positive reactions even in the absence of peroxidase.

Oxidase in the presence of catechol causes oxygen absorption. This can be determined in a Warburg apparatus, which is complex and expensive though it is a good measure of peroxidase activity.

Liberation of iodine from potassium iodide by hydrogen peroxide is accelerated by peroxidase. The acceleration can be measured by titrating the liberated iodine. This method is, however, beyond the ability of the average dehydrater foreman.

Under government specifications, only catalase need be destroyed in the blanching of cabbage; the peroxidase may still be active. Catalase liberates oxygen from hydrogen peroxide. To make the test, proceed as with peroxidase, but do not add the guaiacol or other indicator; add the hydrogen peroxide only. If catalase is still active, bubbles of gas evolving from the surface of the vegetables will rise through the liquid. By testing pieces blanched 10 to 15 minutes in comparison with unblanched pieces, one can readily distinguish between the evolution of oxygen and the few bubbles of air entrapped with the vegetable.

To prepare the hydrogen peroxide used in tests, dilute with distilled water a concentrated pure hydrogen peroxide solution of about 30 per cent H_2O_2, such as "superoxol." Hydrogen peroxide from a drugstore is apt to be weak and unreliable.

Sulfuring and Sulfiting.—Dried carrots, when stored in air, lose their deep golden color because the carotene is oxidized and lost. They decrease, therefore, in vitamin-A potency, since carotene is the precursor of vitamin A. Spinach and cabbage lose vitamin C during drying and storage. Most dried vegetables develop a haylike odor if kept in air. According to experiments in England, Canada, and here, treatment in the fumes of burning sulfur (SO_2 fumes) or dipping in dilute sodium or potassium bisulfite or metabisulfite solution will greatly retard losses of carotene and vitamin C and will prolong the fresh color and flavor of the product for several months. Sulfite or bisulfite solutions are also applied by spraying the product on the trays. SO_2 itself is not to be recommended for leafy vegetables, as here there is an undesirable color change. For actual data on these points, see the section on changes in nutritive value during dehydration.

For best results, both blanching and SO_2 treatment are required. Dipping in a dilute sulfite solution after blanching is the simplest way to impregnate the vegetables with SO_2. Industrially, however, it is frequently least practical. A spray inserted one third of the way down a flat continuous blancher has proved very satisfactory in one plant.[8]

In the fumes of burning sulfur blanched carrots, cabbage, and spinach absorb SO_2 very rapidly. In an atmosphere containing 2 per cent SO_2 the blanched vegetables took up enough in 10 minutes to give 4,000 p.p.m. or more of SO_2 in the dried product. A lower concentration of SO_2 in the sulfuring box is desirable—probably about 0.5 per cent. Dipping in dilute sulfite is simpler

[8] Experience gained in recent months shows that no single procedure is suitable for all plants. Dips, sprays, applied hot or cold, before, during, or after blanching, can be satisfactory provided two relationships are controlled: concentration and temperature; and composition (largely a question of pH) in relation to possible corrosion difficulties.

and permits of closer control. To judge from experiments, a concentration of about 1,000 to 1,500 or even 2,000 p.p.m. of SO_2 in the dried vegetables is satisfactory and does not materially alter the flavor of the dehydrated cooked product.

If stored in air, dried and blanched carrots or cabbage will smell stale and taste stale in 3 or 4 weeks, whereas the sulfured, dried products have retained their normal odor, flavor, and color for more than 3 months even at 90° F.

For a given set of operating conditions, one should determine experimentally the proper concentration of sulfite solution and the proper length of immersion of the blanched vegetables to give the desired level of SO_2 in the dried product.

Although SO_2 destroys vitamin B_1, many vegetables are not a good source of this vitamin; in general the advantages of sulfuring outweigh this disadvantage.

OPERATING THE DEHYDRATER

The various factors concerned in dehydrater operation have been surveyed in previous sections. Working directions will now be given.

Tunnel Load.—In the countercurrent tunnel the cars of trays enter the cooler end of the dehydrater at 95° to 125° F, the temperature depending upon the number of cars in the tunnel, the air velocity, the tray load, and the temperature of the air entering the hot end. If very rapid drying is desired, only a few cars—perhaps 7 or 8—are placed in a tunnel capable of holding 14; and the trays are loaded lightly. In most tunnel dehydraters used for carrots the finishing temperature is about 150° to 155° and the exhaust air temperature about 122° to 125°; for potatoes about 140° to 145° and 120° to 128° respectively. For onions and cabbage the temperatures are lower—130° to 140° at the hot end.

Drying Time.—If a 60-foot tunnel is completely filled with cars of vegetables, the exhaust air may drop to 95° to 110° F. Drying time for each car is prolonged. Because, however, there are more cars in the tunnel, the output per hour may be as great as when fewer cars are used, or greater. The optimum tunnel load must be determined by trial for each dehydrater and each set of operating conditions. Under the two-stage method of dehydration, using parallel-current drying and high temperature in the first stage and countercurrent drying in the second, the drying time can be reduced to a minimum. In the experimental dehydrater, cabbage and Julienne-cut root vegetables have been dried in less than 5 hours at a constant temperature of 145°. In commercial practice, observed drying times ranged from 6½ hours for Julienne-cut potatoes, on lightly loaded trays in partly filled tunnels, to 14 hours for cabbage in completely filled tunnels. Quality suffers when the drying period is unduly long. In an Eastern plant, carrots were dried in about 6½ hours by the two-stage method.

Drying time is markedly affected by the size of the pieces, as already discussed in the section on this subject.

The tray load per square foot also greatly affects the drying rate, as is shown by the data discussed in the section on tray loading.

In commercial practice most dehydraters operate on a strictly observed time schedule. One large plant, for example, leaves each car of diced carrots in the

tunnels 9 hours, the tray load being 1¾ pounds per square foot, and the finishing temperature 150° F. Another leaves cars of Julienne potatoes 6½ hours, the tray load being about 1 pound per square foot and the finishing temperature 145°. Moisture determinations are made frequently; and the time or the temperature of drying is changed if analyses should indicate the necessity.

In plants where the partially dried products are transferred to bins and drying is completed at about 120° F, a time schedule can also be followed.

TABLE 6

MOISTURE CONTENT OF DICED CARROTS AT VARIOUS STAGES OF DRYING IN A COMMERCIAL PLANT

Car number in tunnel	Time in tunnel	Moisture content of carrots in per cent
1	0 min.*	87.9
1	30 min.	86.2
2	1 hr., 20 min.	83.8
3	2 hrs.	79.0
4	2 hrs., 40 min.	69.2
5	3 hrs., 10 min.	58.5
6	3 hrs., 30 min.	58.3
7	4 hrs., 20 min.	34.4
8	5 hrs.	27.5
9	6 hrs.	16.4
10	6 hrs., 30 min.	7.98
11	7 hrs.	7.79
12	7 hrs., 20 min.	6.20
13	8 hrs., 20 min.	5.80

* Before entry into tunnel.

Rates of Drying at Different Locations in the Tunnel.—To obtain information on the drying rate at various points in the tunnel, samples were taken from a fully loaded tunnel of diced carrots under normal operating conditions at a California plant on February 2, 1943; and one sample was taken from a car before it entered the tunnel. The tunnel was being operated countercurrent. The dry-bulb temperature at the hot end was 157° F, and at the cool end 127°; the wet-bulb temperature at the cool end was 88°. The samples were analyzed for moisture content. Table 6 gives these values, together with the lengths of time the cars had been in the drying tunnel. Moisture removal was slow the first 2½ hours. Difficulties in sampling caused irregularities, but the trend, compared with that in the laboratory dehydrater, shows that this plant could shorten its drying time. The data were taken by Balog.

The following data taken for carrots at 150° F in the laboratory dehydrater indicate what might be expected from two-stage operation.

Hours of drying	Approximate moisture content, per cent
0	88.0
1	75.0
2	49.0
3	20.0
4	11.7
5¼	6.0

At 2 hours, in this experiment, the moisture content was 49 per cent, whereas in the commercial plant it had dropped to only 79; and at 3 hours the moistures were 20 per cent and about 60 respectively. These data show that by using high initial temperatures one can greatly shorten the drying time.

Similar data were secured for cabbage and for potatoes being dried commercially by the countercurrent method and also for these vegetables dried at 140° to 145° F in the laboratory dehydrater. The results resembled those for carrots.

Judging the Finishing Point.—When dried to Army specification most vegetables are very dry and brittle at room temperature, although they are somewhat pliable at 130° to 150° F. By cooling a sample a few minutes and then examining it for brittleness, moistness, or mealiness of the interior and for behavior on breaking between the fingers or on chewing, an experienced operator can judge closely whether or not the product is dry enough.

Frequent analyses serve to check the judgment and to prevent serious under- and overdrying.

Determining the Moisture.—The official method of moisture determination consists in drying a finely ground, representative sample at 70° C and 28 to 30 inches' vacuum to constant weight. Present standard procedure of the Food Distribution Administration is to grind an average sample in a thoroughly dried Waring blender in a dry room; weigh about 2 grams of the ground sample quickly to 1/10 of 1 milligram in an aluminum moisture dish of standard diameter (about 2½ inches); and dry 6 hours at nearly 30 inches' vacuum and 70° C. The dish is cooled in a desiccator and quickly weighed to the nearest 1/10 milligram. If the moisture dishes have tight covers, weighing need not be rapid; but the slow weighing of an open dish permits moisture uptake by the dried sample.

In experiments[9] the xylene-distillation method commonly used for dried fruits caused excessive decomposition of the samples of vegetables, with variable and undependable results. The method consists in distilling a 20- or 25-gram sample with xylene into a graduated measuring tube, with a side tube for returning excess condensed xylene to the distillation flask. Toluene causes less decomposition of the sample; but the distillation period is longer because toluene has a considerably lower boiling point than xylene. With a 50 : 50 mixture of xylene and toluene, the results were fairly satisfactory. The procedure recommended is as follows:

Grind an average sample in a dry Waring blender. Weigh exactly 25 grams into a dry 500-cc, short-necked, round-bottomed distillation flask equipped with reflux condenser, graduated receiving tube, and return tube (fig. 18). Before being used, the distillation method must be calibrated against the vacuum-oven method, since the distillation time will vary with the vegetable and with the characteristics of the electric heater. To calibrate the equipment, proceed as follows: To the 25-gram sample in the flask add 150 cc of a 50 : 50 mixture of toluene and xylene. Heat to boiling on an electric flask heater; record the time. Continue distillation, and at 3-minute intervals read the volume of water in the graduated tube. When this volume multiplied by 4 equals the moisture content determined previously by vacuum oven, take the

[9] Conducted by Charles Wilson and J. Sugihara.

corresponding time in minutes as the standard distillation time. Repeat the analysis with a fresh sample and a fresh xylene-toluene mixture to make certain that the procedure can be duplicated. Occasionally, during the season, compare results on subsequent samples against the vacuum oven.

Another approximate method is to place a 5-gram, ground sample in a moisture dish of 2.5 inches' diameter at 100° C (212° F) and dry it in an oven at atmospheric temperature.

A small oven operating at about 235° F is now available. The sample dries quickly—normally in about 3 minutes. The apparatus also must be standard-

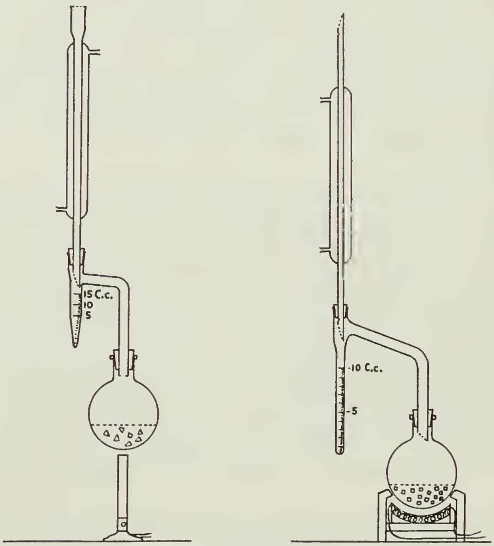

Fig. 18.—Nichols and Reed distillation apparatus for moisture determination by the xylene or toluene distillation method. The apparatus at left is heated by gas flame; that at the right by electric heater. The latter offers much less fire **hazard.**

ized, for each product, against the vacuum oven. The list price f.o.b. New York at present ranges from $52.80 to $81.00, according to size and accessory equipment.

The Dried Fruit Association of California has an electrical-conductivity apparatus for rapidly determining the moisture in dried fruits. This, however, would have to be redesigned for vegetables, where the conductivity at 5 per cent moisture is very low as compared with fruits of 15 to 25 per cent moisture.

The electrical instrument used by the milling industry for quick determination of moisture in flour and cereals has not proved satisfactory, except for examining raw material of relatively uniform chemical composition and of fairly constant physical condition. It is said to give reliable results with dehydrated potatoes but not for onions.

Emptying the Trays.—The trays should be emptied at once after drying is completed. Usually the product must be loosened from them by hand-

scraping—an operation performed by a workman at each end of the tray, by means of a sheet-metal scraper 10 to 12 inches wide. The tray is then quickly emptied by turning it upside down over a hopper, from which the dried product is conveyed to the sorting belt.

Sorting the Dried Product.—Since the Food Distribution Administration and the Army specifications allow only 2 per cent of defects in most dried vegetables, careful sorting is necessary. The dried product is closely inspected as it travels in a single layer on a slowly moving, light-colored belt. Pieces that are dark, still unpeeled, insufficiently dried, or otherwise defective are removed.

Testing for Enzymes.—It is customary to make frequent qualitative enzyme tests of the blanched vegetables before drying, and of the dried vegetables as already described. The Food Distribution Agency uses a special technique obtainable from that agency.

Packaging.—During World War I, dried vegetables for Army use were packed in 5-gallon tin cans with a tin disk soldered over the opening in the top. At present most dehydrated vegetables for Army use are placed in 5-gallon, wide-mouthed tin cans with the lids sealed on by a mechanical can seamer. Two cans are packed in a strong case. After each can is filled with carrots or cabbage, carbon dioxide gas is admitted to the bottom by tube from a cylinder of the liquefied gas, displacing most of the air. Specifications require that less than 2 per cent of oxygen be present in the atmosphere in the sealed can. Under the rather haphazard method now in use, the amount of CO_2 added varies greatly; according to Chace (1942) and others, the atmosphere in the can may greatly exceed 2 per cent of oxygen. The Canadian practice is much better than the American: their specifications require that the container be exhausted to 29 inches' vacuum, and the vacuum released with carbon dioxide or nitrogen, these operations being repeated twice. Both carrots and cabbage, unless sulfured, are very sensitive to oxidation; hence the use of carbon dioxide. The U. S. Army calls for certain weights of the various vegetables per 5-gallon can. (See the section on regulations and specifications.)

Other dried vegetables for Army use may be packed in one of several approved special, laminated bags. One of these consists of layers of Kraft paper, asphaltum, cellophane, and lead foil. The bag, being heavy, is proof against water, though not against punctures or tears in filling or handling, nor against rodents and boring insects. It is satisfactory for use in the United States and under not too severe conditions overseas for potatoes, beets, sweet potatoes, rutabagas, and onions.

After World War I, dried vegetables for the civilian market were packed in ordinary dried-fruit cartons of the type now commonly used for raisins. The cartons were sometimes lined with glassine or wax-paper bags. Since they were not waterproof, the contents absorbed moisture and then deteriorated rapidly in color, odor, and flavor; also, since they did not exclude insects, the packages became infested, and consumers lost confidence.

In Europe, dried vegetable soups have for years been compressed and sold in Bologna-sausage-shaped packages or in bricks. These appear to be less subject to insect attack.

Recently one firm has marketed riced potatoes in friction-top cans and in

cellophane-lined cartons; and at one time dehydrated pumpkin was sold in friction-top cans. These products kept well.

In the past three years J. D. Ponting and W. V. Cruess (unpublished data) have stored dried fruits very successfully in plastic-impregnated, foil-lined, cardboard "cans" with metal ends sealed in place on a tin-can sealer. In a typical test, 836 grams of prunes of 25 per cent original moisture content lost 22 grams in weight when stored in a dry room at 83° to 90° F for 12 months, a loss in moisture of 2.7 per cent. Loss in the usual dried-fruit cartons is much greater in 4 weeks.

A very satisfactory container, used in 1941 for dry noodle soup and dried vegetable-soup mixes in the civilian trade, consisted of a sealed pliofilm plastic bag covered with heat-sealed heavy aluminum foil. At present, during critical shortages of aluminum foil and pliofilm, a satisfactory substitute has been used—a cellulose plastic bag inside a lead-foil bag.

Lately E. Balog and W. V. Cruess (unpublished data) found water to be effectively repelled by wooden boxes heavily impregnated with a hot, molten mixture of gilsonite, high-melting asphaltum, and paraffin; or with a mixture of the first two.

After the treatment just described the boxes were cooled, packed with dried vegetables, and nailed, the seams then being coated with the molten mixture. After several days' immersion of the boxes in water the contents were still dry.

Some Army rations are packed in heavy cartons coated with a tough, white wax that renders them more or less waterproof.

Large drums of enameled black iron, sealed with a rubber gasket, are used for storing dried vegetables in bulk; if available, these could be used for overseas shipments to the Army and for similar purposes. They can be made airtight and moistureproof.

Recently Pitman, Rabak, and Yee (1943) have reported extensive experiments with various packaging materials for dehydrated vegetables. They stored many different packages in air of high relative humidity and tropical temperature. They recommend: "For year-long storage in the tropics the moisture pick-up by dehydrated vegetables in a container to be substituted for metal, should not exceed 2 per cent of the original weight of the package contents." L. K. Harper (1942) makes a similar recommendation. In displacing air with carbon dioxide they recommend that a gas meter be used and that at least 1 cubic foot of the gas be added to each 5-gallon can. They found also that solid carbon dioxide could be used to advantage, if suitable precautions were observed. Very few packaging materials other than metals proved sufficiently moistureproof to prevent a 2 per cent increase in moisture content per year under tropical conditions. Several, however, did so for 4 months, including Pliofilm; duplex and triplex bags of moistureproof, heat-sealing cellophane; a special cellophane laminated to cellophane; and coated, laminated glassine. These investigators expressed the water-vapor permeability, K, as "grams of water diffusing through one square meter of the material per 24 hours per millimeter of mercury water vapor gradient across the material"; and the water-vapor resistance, R, as $1/K$. A water resistance of 17 or above was found necessary to prevent a 2 per cent increase in moisture content of the dried vegetables in 12 months under tropical conditions.

Compressing Dehydrated Vegetables.—Dehydrated vegetables are bulky and occupy much space per pound of dry material. Pitman, Rabak, and Yee (1943) give information on weights of several dried vegetables per cubic foot and per 5-gallon can. (See table 7.)

E. Balog (unpublished data) has shown that if cabbage warmed in a dehydrater or taken off the trays while warm is compressed at once while still flexible, its weight per unit volume can be much increased without serious shattering of the pieces. If left unheated, however, it shatters badly when compressed. For compressing the dried vegetable into sheet-metal, cylindrical forms slightly smaller in diameter than the cans, the equipment used consisted of a small hand press designed to crush apples for juice, together with hardwood cylinders of slightly smaller cross section than 8-ounce and number 2½

TABLE 7

Bulk Densities for Several Dried Vegetables*

Vegetable	Condition	Pounds per cubic foot	Pounds per 5-gallon can
Beets	3/16-inch slices	15	10
Cabbage	Shredded	7½	5–7
Carrots	3/8-inch cubes	21	14
Onions	Flakes	14	9–12
Potatoes	Cubes	24	16
Potatoes	Strips	15	10
Sweet potatoes ("yams")	¼-inch slices	18	12

* Data from Pitman, Rabak, and Yee (1943).

cans respectively. The resultant cakes, ½ to 1 inch thick, were then sealed into cans. In a typical experiment, an 8-ounce can held 32 grams of loose-pack dried cabbage and 146 grams of compressed; the ratio was about 4.5 :1. On this basis a 5-gallon can would hold over 23 pounds instead of the usual 5 to 7.

Potatoes in Julienne strips shattered badly whether heated or not before compressing. If placed for ½ to 1 minute in live steam, they could be compressed into dense cakes without appreciable shattering. After steaming they contained about 8 per cent moisture. It required about 3 hours' drying at 150° F and about 8 to 10 per cent relative humidity to reduce them below the 7 per cent maximum moisture content allowed by the Army. An 8-ounce can held 68 grams of the loose pack or 246 grams of the compressed, a weight ratio of 1 to 3.6. The product refreshed and cooked readily in water. All the potatoes in the compressed blocks must be dried below 7.0 per cent moisture.

Dried, diced carrots heated in a commercial tunnel to about 150° F in dry air were readily compressed. On cooling, however, the cakes soon crumbled (pieces separated) ; immediate packaging would be necessary. The ratio of loose pack to compressed was about 2 :1.

Onions in qualitative tests compressed very readily if previously warmed in moist air.

Proctor (1942) has compressed various vegetables into rectangular blocks and has wrapped them in cellophane. Pitman and associates (1943) at the Western Regional Laboratory of the U. S. Department of Agriculture have

also done much work on this problem. Both these laboratories have correlated final weight per volume with pressure in pounds per square inch. Proctor used pressures as high as 1,100 pounds, though he recommends a figure lower than this for most products. In Balog's tests (previously cited) the pressure per square inch was probably 300 to 500 pounds. Recently, using a Carver laboratory press, he has correlated pressure per square inch against density of the compressed products, with results that agree well with Proctor's and others.

As various research agencies have shown, most dehydrated vegetables can be compressed, with great saving in packaging materials and cargo space, and probably with considerable increase in resistance to oxidative changes and insect damage. Also, these vegetables can be readily refreshed and cooked, unless excessive pressures have been used.

Storage.—Dried fruits are kept in warehouses in open bins or boxes. If storage is prolonged, the fruit is fumigated regularly in tight chambers or rooms. For vegetables such storage is not recommended, less through fear of insect infestation than because moisture may be absorbed from the atmosphere, with consequent speedy deterioration in color and flavor.

It is advisable, therefore, if storage becomes necessary through a lack of final packages, to place the dried vegetables in sealed, moistureproof containers—sometimes in inert gas. Large drums of enameled black sheet iron, fitted with special compression closures and rubber gaskets, are generally used for bulk storage and bulk shipment of powdered and flaked tomato soups and cocktail, also for vegetables for soup mixtures. In some cases the filled drums are evacuated, and the vacuum released with nitrogen or CO_2. If available, such containers are better than open bins or boxes for bulk storage of dried vegetables.

Moisture Content versus Insect Infestation.—Dehydrated vegetables low in moisture are not attacked by insects. The limiting moisture content below which growth will not occur is not accurately known, but is less than 10 per cent. In experiments by Christie and Woodworth (1923) with dried fruits, the common dried-fruit insects did not thrive at less than 12 per cent moisture.

For vegetables, probably, the minimum moisture content for insect growth is considerably lower than for fruits, because vegetables contain fewer soluble solids and a much larger proportion of insoluble ones. For the "sirup" in the dried vegetables to attain a concentration and an osmotic pressure sufficient to prevent insect growth, the total moisture content must be much less than in fruits—possibly below 7 per cent for potatoes and below 5 per cent for other vegetables. Experiments now being conducted by Dr. A. E. Michelbacher of this University are designed to establish the minimum moisture content for insect growth in various dried vegetables.

DIRECTIONS FOR DRYING THE VARIOUS VEGETABLES

Research is fast advancing our knowledge of vegetable dehydration; our present practice will change. For blanching, peeling, cutting, and other operations, see discussions earlier in this bulletin. A summary of procedures for the vegetables is given in table 8 (p. 64–65).

Asparagus.—Unless it is garden fresh, dehydrated asparagus is apt to be bitter. Green asparagus is more satisfactory than white. Only the tender tips

should be used. Discard the stalks; even if tender, they will not rehydrate after drying. Wash thoroughly. Blanch in live steam for 10 minutes; then cut in short lengths ¼ to ½ inch. Load the trays 1 to 1½ pounds per square foot. Dry to less than 5 per cent moisture at not above 145° F.

A fairly satisfactory soup stock can be made by powdering in a hammer mill. When made from green asparagus the powder should be packed in vacuum or inert gas.

Globe Artichoke.—Remove the outer bracts, and use only the tender hearts. Trim the stem end. Cut the hearts in half lengthwise. Blanch in live steam until practically cooked—normally about 15 minutes. Load the trays about 1½ pounds per square foot. Dehydrate to less than 5 per cent moisture, finishing at not more than 145° F. The color is better if the artichokes are blanched in 0.5 per cent citric acid solution, or dipped in it briefly after steaming. Packing in air is satisfactory. The dried product is not very satisfactory.

Jerusalem Artichoke.—This root vegetable of the sunflower family is in demand among diabetics because it contains inulin, a starchlike substance that gives levulose sugar on digestion.

Peel in an abrasion peeler. Trim. Dice, slice, or cut in Julienne strips. Wash. Blanch about 6 minutes in live steam. Load the trays 1 to 1½ pounds per square foot. Dehydrate to less than 5 per cent moisture at not above 145° F. There is no need to pack in vacuum or inert gas.

Green String and Stringless Beans.—As previously stated, the best bush varieties of green beans, such as Stringless Greenpod, gave better products than did the Kentucky Wonder and Blue Lake pole varieties. Only fresh, tender pods should be used.

Trim off the ends; with the stringless varieties, this work can be done by canning machinery. Cut into lengths of 1 to 2 inches. For quick drying, cut the pods lengthwise.

Blanch in steam until practically cooked—about 20 minutes for best results.

The tray load should not be too heavy—about 1 pound per square foot. Beans respond well to two-stage dehydration; drying may begin at 175° F or higher. Dry to less than 5 per cent of moisture, finishing at not above 140° F. There is no need to pack in vacuum or inert gas.

Although string beans dry well after even a short blanching, the dried beans are then apt to cook slowly. They refresh and cook much more rapidly if blanched enough to be served at the table.

Fava Bean (Horse Bean).—These beans, popular among people of Mediterranean origin, are grown in California rather extensively as a winter and early spring crop. They may be shelled by machine from the pods; hand-shelling is laborious and too costly for commercial dehydration.

Blanch the shelled beans in live steam 6 to 10 minutes—enough to destroy all peroxidase activity, for the beans blacken rapidly if bruised in shelling. For the same reason, blanch promptly after shelling. Dehydrate to less than 5 per cent moisture, finishing at not above 145° F. The beans need not be packed in vacuum or inert gas.

Lima Bean.—Use any good canning or freezing variety, though the smaller kinds (baby limas) dry faster and are less apt to burst in drying than the large ones. When dried, a green variety is more attractive than a light-colored one.

The vines are harvested by machinery, much as are pea vines; and the beans shelled mechanically from the pods on the vine by equipment similar to that used for peas.

Sort carefully on a belt to remove overmature beans, pieces of pods, and the like. Blanch thoroughly 8 to 10 minutes in live steam. Load the trays 1 to 1½ pounds per square foot. Dry to less than 5 per cent moisture, finishing at not above 150° F. The beans need not be packed in vacuum or inert gas.

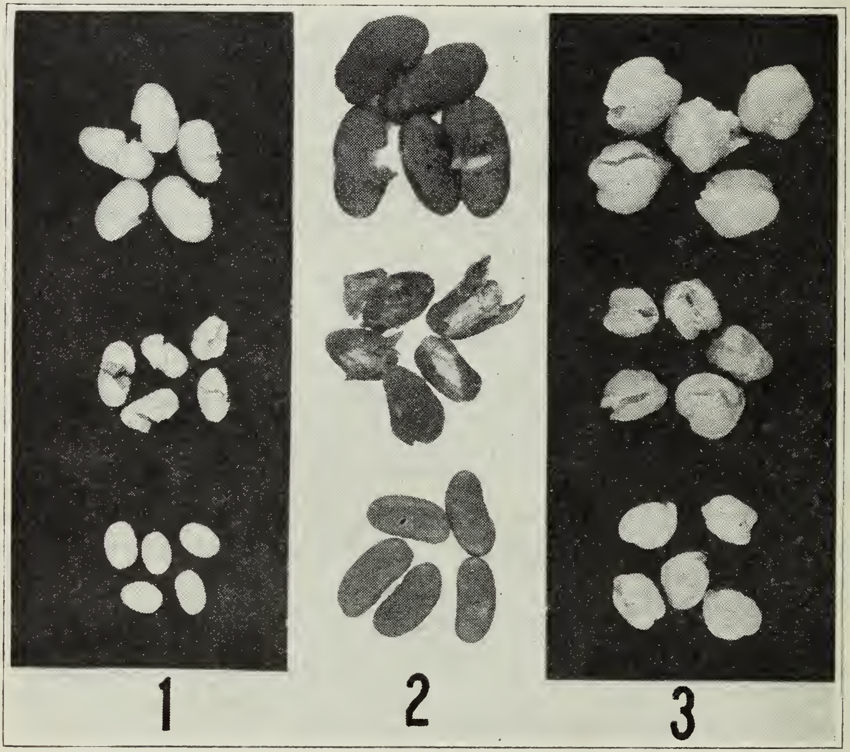

Fig. 19.—Bottom row, natural beans. Middle row, precooked, dehydrated beans. Upper row, precooked, rehydrated beans. The types or varieties are: 1, Small White navy; 2, Red Kidney; and 3, Garbanzo or chick-pea. The long soaking time prior to consumption is avoided by the preliminary soaking and pre-cooking. After the cooked material has been dehydrated, it can be quickly prepared for eating.

Dry Beans, Precooked and Dehydrated.—The Army, under campaign conditions, needs foods that will cook quickly. Dry beans such as White navy and Red Kidney, in their natural state, are therefore not very suitable; they require several hours of soaking and cooking. The Quartermaster Corps has now issued specifications for precooked dehydrated beans for Army use, based on experiments here and in other laboratories. Examples of natural dry, dehydrated, and rehydrated beans are shown in figure 19.

The beans must be soaked thoroughly before being cooked for drying. The following general directions can be modified as conditions require: Sort the beans carefully on a slowly moving belt to remove small stones, weed seeds,

broken beans, stained beans, and other unfit material. Wash them thoroughly to eliminate dust and bits of straw. To each 100 pounds add about 25 gallons of cold water. Soak about 16 hours in enough water to plump them to full size.

Drain. Steam until thoroughly cooked; the garbanzo (chick-pea) takes longer than others. Soaked beans of all varieties may be cooked in wire baskets in closed retorts by steam under pressure at 240° F, the time being 5 to 10 minutes. Overcooking must be avoided, for it causes mealiness.

Dehydrate to less than 5 per cent moisture. Rather high drying temperatures (160° to 170° F or above) can be used. Any liquid left from soaking may be boiled down to a thick gravy and added to the beans in drying.

The raw beans may be cooked as for the table—as Boston baked beans, for example, or in Mexican style with hot sauce, peppers, onion, and garlic. Omit the usual pork or other meat; it will rancidify after drying. In cooking beans in these or other ways, use as little liquid as possible; and in drying, concentrate the liquor separately to a gravylike consistency and add it to the beans on the trays at the hot end of the tunnel, allowing it to dry with them. Do not overcook the beans before drying. Dehydrate to less than 5 per cent moisture. Temperatures may be as high as 160° to 175° F.

Esselen and Davis (1942) describe a procedure for preparing and dehydrating Boston baked beans. The beans are soaked, have a sauce added, and are baked and then dehydrated on waxed paper or in shallow pans.

Beets.—Only tender beets, deep red, free from woodiness and from prominent white rings in the flesh, should be used. Wash thoroughly in a spray, rotary washer. Steam until cooked through, usually 20 to 30 minutes, with roots and trimmed tops in place; or cook a shorter time in a retort at 240° F under steam pressure. Allow to stand about 2 hours to allow equalization of the color. Peel by hand, removing the roots and tops; or peel the raw beets in an abrasion peeler, like potatoes.

Cube, slice, or cut in Julienne strips with an Urschel slicer or similar machine. Beets cooked before peeling require no further blanching; those peeled raw must blanch in live steam about 10 minutes. The tray load is 1 to 1½ pounds per square foot.

Dehydrate to less than 5 per cent moisture at not above 150° F. With care a higher finishing temperature (155° to 160°) can be used, because beets are not extremely sensitive to heat. They need not be packed in vacuum or inert gas.

Broccoli.—This popular winter vegetable responds well to dehydration. In that process its principal shortcoming is a tendency for the small buds to shatter off the stalks after drying. It retains its color and flavor better than does cabbage.

If the stalks are large, cut in half lengthwise. Blanch in steam for about 10 minutes; do not overblanch. Load the trays 1 to 1¼ pounds per square foot.

Dehydrate to less than 4 per cent moisture. The finishing temperature is preferably not above 140° F, although 145° can be used if great care is exercised. Dried broccoli need not be packed in vacuum or inert gas.

Brussels Sprouts.—Cut from the stalks, sort, and trim. Cut the sprouts in half lengthwise. Blanch long enough to destroy the catalase enzyme—usually 5 to 6 minutes. Do not overblanch. Load the trays 1 to 1½ pounds per square foot. Dehydrate to less than 4 per cent moisture at not above 140° F.

The sprouts are sensitive to heat injury. Since they deteriorate rapidly after drying if stored in air, they should be packed in vacuum or inert gas. Light sulfite treatment before drying will preserve the color and flavor. Unless they are sulfited, pack them in neutral gas or vacuum.

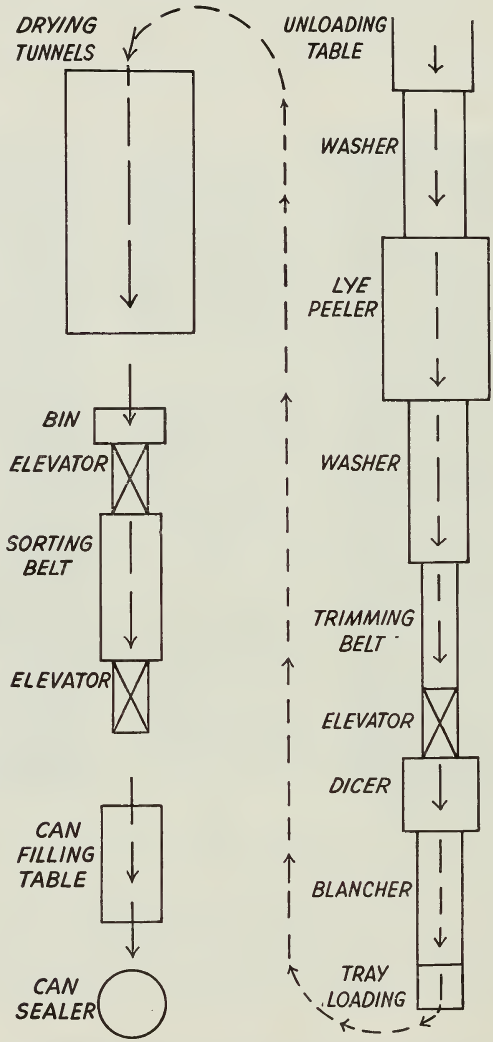

Fig. 20.—Flow sheet for dehydration of carrots.

Cabbage.—Normally, dehydrated cabbage is not needed for civilian use; but at present it is in demand for the Army.

Choose varieties that give a dried product of pleasing flavor and color. The Savoy and similar loose-headed cabbages are best, although Copenhagen Market and Glory give good products. The Flat Dutch is not very satisfactory. Process promptly after harvesting. Remove the outer leaves. Use a mechanical corer. Shred in a kraut slicer to strips about $\frac{3}{16}$ inch wide, somewhat wider

than for kraut. Blanch on the trays, as blanched cabbage is difficult to spread out. Blanch in live steam until catalase is destroyed and some peroxidase remains. For small laboratory lots, 2 minutes' steaming suffices; but on wooden trays 6 or 7 minutes will be required. Be guided by catalase and peroxidase tests. Dipping for 20 to 30 seconds in 0.25 per cent sodium bisulfite solution after blanching stabilizes color, flavor, and odor. The Army will probably require this treatment soon. The tray load is 1 pound or less per square foot.

Since cabbage when nearly dry is sensitive to heat, finish at not above 140° F. Parallel current is effective in the early stages of drying; it may be started at 175° to 190°. Reduce to less than 4 per cent moisture.

As dried cabbage deteriorates rapidly in air, it should be packed in vacuum or inert gas; the Army so specifies.

Carrots.—A flow sheet for carrots is seen in figure 20. For dehydration, carrots should have deep, uniform color and good flavor. The Red Cored Chantenay, Imperator, Nantes, Danvers Half Long, and Morse Bunching have proved satisfactory in the tests. (See the section on varieties.) They are picked at sacking size and delivered without tops to the plant in lugs or sacks. They should be used promptly, for wilting seriously injures them. Wash thoroughly in a potato brush-and-spray or drum washer so that the adhering soil will not accumulate in the lye-peeler and interfere with heating the lye solution.

Next, peel the carrots in a boiling solution of about 3 to 10 per cent sodium hydroxide. Salt may be added to increase the boiling point of the lye. A cannery lye-peeling machine for peaches can be used; or a continuous grape dipper can be converted into a lye-peeler. One plant uses a Dunkley spray lye-peeler. The period of immersion is usually 10 to 60 seconds. Wash thoroughly in a drum-and-spray washer to remove disintegrated peels and lye solution.

Trim on a slowly moving belt, removing any green portions near the crown and trimming off roots or blemishes. In one California plant, ten to twelve women trim satisfactorily more than a ton of peeled carrots per hour.

Cut the carrots in an Urschel or similar dicer in cubes about 3/16 to 3/8 inch in size.

Place in a continuous blancher in live steam for at least 7 minutes; 10 to 15 is better. Spread on trays at the rate of about 1½ pounds per square foot. Dry to less than 5 per cent moisture, finishing at not above 155° F (although, with care, 160° can be used).

Test the blanched carrots occasionally for peroxidase by using benzidine and hydrogen peroxide. Peroxidase should be destroyed in blanching. Guaiacol indicator is unsatisfactory because it is masked by the color of the carrots.

Carrots lend themselves well to two-stage drying—that is, drying first by parallel current at about 185° F at the hot end, and then by countercurrent, finishing at 155°.[10] Under this system, the drying time in Canada is 4 to 5 hours. In a California plant using countercurrent throughout and finishing at 155°, the time is about 9 hours; in another about 11. (See also the section on temperatures and moisture content in various parts of the dehydrater.)

By three-stage drying, in an eastern plant, the carrots are dried first by parallel current, then by countercurrent; the last 3 to 5 per cent of moisture is removed in bins with desiccated air.

[10] Personal communication from F. E. Atkinson.

Sort the product, eliminating fines by passage over a screen. For Army use, pack in inert gas and seal hermetically in cans. Dried carrots stored in air deteriorate rapidly in color, flavor, and odor.

If the containers admit air, conserve the carotene and the flavor by sulfuring in SO_2 fumes or by dipping the blanched carrots in dilute sodium bisulfite to give about 2,000 p.p.m. of SO_2 in the dried product.

Cauliflower.—Results with this vegetable have not been very satisfactory. In storage after drying, cauliflower is inclined to darken and acquire a strong flavor. A light treatment with fumes of burning sulfur or a dip in dilute bisulfite solution before drying will check the darkening and is advisable in commercial practice.

Cut stalks from heads. Trim. Cut in half lengthwise to facilitate drying. Blanch till catalase is destroyed. Load the trays 1¼ to 1½ pounds per square foot. Dehydrate to less than 4 per cent moisture, as for cabbage, finishing at not above 140° F.

The dried cauliflower, unless sulfured or sulfited, should be packed in vacuum or inert gas.

Celery.—Dried celery leaves, whole or powdered, are a useful flavoring for stews, soups, meat loaves, poultry stuffing, and other dishes; and the dried cut stalks are satisfactory in preparing cooked celery. Both the stalks and leaves may be ground and mixed with salt for use as celery salt.

Use only fresh, crisp heads. Break the stalks apart. Wash thoroughly to remove all spray residue and soil. For best results, trim and remove the strings by hand. Since the leaves dry rapidly, dry them separately from the stalks.

Cut the stalks in short lengths—⅛ to ½ inch. Blanch in live steam 1 to 2 minutes; longer blanching impairs the flavor. Load the trays 1 to 1½ pounds per square foot for stalks. Dehydrate to less than 5 per cent moisture, finishing at not above 145° F. For powdered celery, omit the blanching. Dried celery need not be packed in vacuum or inert gas.

Celery Root.—Wash, trim, and peel. Cut in Julienne strips, thin slices, or ⅜-inch cubes. Blanch thoroughly 8 to 10 minutes in live steam. Load the trays 1¼ to 1½ pounds per square foot. Dehydrate to less than 5 per cent moisture at not above 150° F. The product need not be packed in vacuum or inert gas.

Chard.—Sort and trim. Wash the leaves very thoroughly. Blanch 5 to 6 minutes—preferably on the trays, since it is hard to spread the leaves after blanching. Load the trays 1 pound or less per square foot. Dehydrate to less than 5 per cent moisture, finishing at not above 150° F. The dried chard need not be packed in vacuum or inert gas.

Chayote.—This summer vegetable, grown on vines in southern California, is used much like summer squash. It is popular in India, according to students from that country.

Wash and trim; then cut in large segments. Slice these crosswise in pieces about ⅜ inch. Blanch 5 to 6 minutes, preferably on the trays. Load the trays 1 to 1¼ pounds per square foot. Dehydrate to less than 5 per cent moisture, finishing at not above 145° F.

Corn.—As already mentioned, the new hybrid yellow varieties of Golden Bantam proved highly satisfactory in the tests. Country Gentleman, a white variety, and its hybrids are also acceptable.

Pick the ears while the kernels are tender. Use a commercial cannery husker. Trim to remove worm-damaged portions and other unfit material.

Blanch on the cob in live steam about 20 minutes to cook the kernels completely. Remove from the cob with a cannery corn cutter to give whole kernels rather than the cream style. Load the trays 1¼ to 1¾ pounds per square foot.

Dehydrate to less than 5 per cent moisture, finishing at not above 160° F. Corn withstands fairly high temperatures.

After drying, remove silks, bits of cob, and other light material by fanning mill or by a suction fan.

As corn retains its flavor and color well, even in air, it need not be packed in vacuum or inert gas; but it should be protected against insects.

Eggplant.—This vegetable dehydrates very satisfactorily. Too prolonged blanching, however, makes it mushy.

Peeling is optional for this vegetable.

Cut in halves or in quarters. Slice these crosswise in pieces about 3/16 inch thick. Or, if the eggplants are not very large, slice them whole into pieces 3/16 to ¼ inch thick. Blanch 4 to 5 minutes in live steam, preferably on the trays; or barely long enough to destroy peroxidase. Load the trays about 1 pound per square foot.

Dehydrate to less than 5 per cent moisture, finishing at not above 150° F.

Garlic.—Considerable hand labor is necessary in preparing garlic to be dried for use whole or sliced, but much less if the product is powdered garlic.

For powdering, break the "buttons" or "cloves" apart; discard the roots. Many of the paperlike husks can now be removed by tumbling the "buttons" in a rotating screen cylinder under a blast of air. Load on trays, and do not blanch. Dehydrate to less than 4 per cent moisture, finishing at not above 140° F. Remove the remaining husks by air suction. Powder by hammer mill in a dry air-conditioned room, and sift to remove coarse particles. Seal in tight containers to prevent moisture uptake with subsequent caking and deterioration in color, odor, and flavor.

If the garlic is to be packed in slices, separate the fresh buttons carefully, eliminating most of the paper husks before slicing and drying. After drying, sort carefully, and remove the remaining husks by suction fan.

Greens (Kale, Beet Tops, and Mustard Greens).—Sort and trim the leaves. Wash vigorously in a rotating drum washer to remove all sand, soil, and insects. Load the trays 1 pound or less per square foot. Blanch kale and beet tops 3 to 5 minutes, mustard greens 8 to 10 minutes—preferably on the trays, since the blanched leaves are difficult to spread. Dehydrate to less than 5 per cent moisture, finishing at not above 150° F.

Leek.—Both the leaves and the bulbs of leek are useful as flavoring. Trim off the roots and leaves. Slice and tray the leaves and bulbs separately. Load the trays 1 pound or less per square foot. Do not blanch. Dehydrate to below 4 per cent moisture, finishing at not above 140° F.

Mushrooms.—For commercial dehydration, cultured mushrooms should be used; the wild ones vary in quality, and poisonous toadstools may be picked by mistake.

Use freshly gathered mushrooms, preferably small. Cut off the stems; these, if tender, may be sliced and dried also.

Blanch in steam 5 to 10 minutes. Load the trays 1 to 1¼ pounds per square foot. Dehydrate to less than 5 per cent moisture, finishing at not above 150° F.

Most dried mushrooms on the market have not been blanched and, though more attractive in appearance than the blanched product, are tougher and of less desirable flavor. Very large mushrooms should be peeled and sliced before dehydration. Dried mushrooms keep well, even in air.

Okra or Gumbo.—This vegetable is often used to thicken and flavor soups and stews. There are several commercial varieties, three of which grown at Davis in 1942 proved very satisfactory for dehydration. Sort and trim the pods. Slice crosswise into 3/16- to ¼-inch lengths. Blanch 5 to 6 minutes in live steam. Load the trays about 1¼ pounds per square foot. Dehydrate to less than 5 per cent moisture, finishing at not above 150° F. The dry product keeps well in air.

Onions.—Dehydrated onions are flaked or powdered. They are much in demand by the armies of the Allied Nations. Before the present World War, both forms were used by soup manufacturers, by meat packers, and by some hotels and restaurants.

Varieties differ markedly in their suitability for dehydration. As mentioned above, the Southport White Globe, the Ebenezer, and the Louisiana Creole are among the best of the important commercial varieties, although the last two are not common in California.

Fresh onions may be stored in a well-ventilated cool room; but they should not be kept long enough to rot or sprout, as they are then unfit for making a first-class dried product.

With a short-bladed knife cut off the crown and roots, together with the woody portion above the roots. Slice mechanically into pieces about ⅛ inch thick. Spread on trays at the rate of 1 to 1¼ pounds per square foot. Do not blanch. A short exposure to the fumes of burning sulfur, or dipping in dilute sulfite, stabilizes the color.

Dehydrate to less than 4 per cent moisture, finishing at not above 135° F. Since onions when nearly dry are extremely sensitive to high temperatures, 125° to 135° is more desirable at the finish than 140°.

In most plants, the onions are dried to the point where they will not mat or stick together and are then finished in bins at about 110° to 120° F with desiccated air. This procedure prevents scorching and greatly increases the capacity of the tunnels.

Onions are packed in air, though their color and flavor are better retained in vacuum or inert gas.

Parsnips.—Parsnips may be prepared and dried like carrots. They keep somewhat better.

Peas.—Fresh, young, tender peas of good varieties are highly satisfactory if well blanched and dehydrated. They were found to surpass the canned in flavor, color, and texture. Sweet rather than starchy peas should be used.

Harvest the vines at optimum average maturity. Shell the peas from the pods on the vine with a pea-vining machine. Transfer at once to the dehydrating plant. Sort carefully on belts. The peas may be size-graded by mechanical grader and automatically segregated by brine flotation into three quality grades with regular cannery equipment. Such grading is unnecessary; if the

obviously overmature peas are removed by hand sorting, the remainder make an acceptable "garden run" pack.

Blanch in live steam until almost sufficiently cooked for serving. The time is 10 to 15 minutes according to size, variety, and maturity; it may be as short as 5 minutes for small, tender peas. Load on trays at the rate of about 1 pound per square foot. Dehydrate to less than 5 per cent moisture, finishing at not above 150° F. Because of hardening of the outer tissues, peas dry very slowly toward the end of the process.

Sort the dried product. Pack in insectproof containers. Inert gas is not necessary, as the peas are apparently not injured rapidly by oxidation.

Peppers and Pimentos.—These are usually dehydrated whole without blanching. They will dry much more rapidly if cored, or cut in half, or sliced, or flame-peeled. A potential market may exist for one or more of these products not now produced commercially.

Hot, dried peppers are popular with the Mexicans of California and other southwestern states and are also needed for making cayenne pepper (red pepper). Dried pimentos are used chiefly for paprika powder.

The usual chili drier is of the kiln type, consisting of a furnace and heating pipes below the ground level. Cars of coarse-screen trays of peppers stand above the heating system. The hot air rises through the trays, escaping through several stacks in the roof. An attempt is made to keep the temperature about 180° F. Drying is slow and uneven; the peppers on trays near the bottom of the cars dry faster and are apt to overdry and to scorch. First-quality dried peppers must be bright red, free from scorching and darkening.

Holmes (1936) has described the drying of peppers in modern air-blast dehydraters, consisting of two tunnels side by side. The first tunnel receives the fresh peppers, 1 ton per car. The air enters this tunnel at 180° F, where much of the moisture is removed. Heated air enters the second tunnel at 150°, and in it the cars of partially dried peppers from first tunnel are placed for finishing. Thus there is no scorching, and the drying is rapid. The time is reported as 20 hours; the processing cost per dry ton about $13. The drying ratio is about 4 to 1.

Chili peppers are apt to darken badly in drying if the relative humidity is high. To prevent darkening, some operators do not recirculate the air.

Since the peppers must be sprayed with lead arsenate to control the pepper weevil, they must be washed in dilute hydrochloric acid and then in water to remove the spray residue. Machinery manufacturers can supply such washers, which resemble those used for pears and apples.

As a new dried product, which can be stuffed in the usual manner after rehydrating, green pimentoes or bell peppers may be prepared as follows: With a short-bladed knife remove the stem and the core. Leave some of the seeds. Blanch 3 minutes in steam. Dehydrate to less than 5 per cent moisture, finishing at not above 150° F. To use for stuffing, soak in water until well rehydrated, and drain. The resultant pepper, though somewhat flabby, can be stuffed.

Potatoes.—At present more white potatoes than any other vegetable are dehydrated for Army use. Since the drying ratio is low, the yield of dry per 100 pounds of fresh is higher than for most other vegetables.

The potatoes should be high in starch, and not soggy after cooking. Quality is greatly affected by variety and locality. In the West the potatoes of Idaho, the Klamath Lake region, the Tule Lake Basin, and sections of similar climate and soil are preferred by the dehydration industry to those grown in the Delta region of the Sacramento and San Joaquin rivers. The potatoes should be well matured, free from rot and of sprouts. After prolonged storage they are much less desirable material than if dried soon after digging. A few rotten specimens will spoil the flavor of a whole sackful.

For dehydration, as previously stated, Netted Gem (Russet Burbank) has given the best results in the variety tests, and is preferred commercially. White Rose, grown under favorable conditions, is also acceptable. These are the two most important varieties in this state.

Until recently most of the potatoes dehydrated in California were peeled mechanically by abrasion (as already described in the section on preparation). The waste by this method is, however, excessive—normally over 20 per cent. In addition, disposal of the gratings is a problem, for they and the wash water putrefy rapidly and produce foul odors. Several plants have been closed temporarily by federal authorities on this account.

Recently lye-peeling of potatoes has come into prominence. A 10 to 15 per cent solution is commonly used. The peeling losses are much lower. In experiments a 15 per cent solution proved superior to a 10 per cent one, since it peels more quickly, without cooking the flesh to any greater depth. The loss in a 15 per cent solution, with a 30-second immersion, was 3.6 to 5 per cent; in the 10 per cent solution it was 8.9 to 18.5 per cent, according to the time required for complete peeling.

In recent experiments of Mazzola (1943), solutions of above 20 per cent sodium hydroxide (caustic lye) gave much better results than the weaker solutions. Peeling losses were reported as 3 to 12 per cent. With such concentrated solutions, some means must be used to keep the potatoes submerged; the density of the bath is much above that of the potatoes, and they must not remain longer than is necessary to disintegrate the skins. The Dunkley spray-peeling machine would probably be helpful; one company now uses it successfully with a 15 per cent solution.

After lye-peeling by any of these methods, the potatoes must be quickly cooled and rinsed in strong sprays of cold water in a rotating drum washer. Too prolonged immersion in the lye, or too slow cooling, results in a layer of cooked, yellowish flesh $\frac{1}{32}$ to $\frac{1}{16}$ inch deep, which may discolor the dried Julienne strips or cubes.

The flame-peeler described in the section on preparation can also be serviceable. This device is used in Canada; and meat-packing plants in this country have installed it to peel potatoes for canned hash and similar products. The following procedure is recommended:

Use only sound potatoes of good quality, free from rot, foul odor, and sprouts. Wash thoroughly in a brush-and-spray potato washer like that used to prepare potatoes for sacking.

Peel by immersing in or spraying with a 15 per cent lye solution. Wash at once in a rotating drum washer equipped with sprays of water under heavy pressure and in ample volume. If there is a tendency to darken or yellow at the

surface, rinse also in dilute (0.5 per cent) hydrochloric acid solution, followed 30 to 60 seconds later by cold water.

Trim the potatoes on a slowly moving belt to remove bruises, rot, eyes, and bits of peel. A tomato-coring knife or an apple-peeling knife is helpful.

Cut in Julienne strips $\frac{3}{16} \times \frac{3}{16}$ inch or $\frac{3}{16} \times \frac{3}{8}$ inch in cross section, using an Urschel slicer or similar machine, or in $\frac{3}{8}$-inch cubes.

Wash under sprays of water on a woven-wire belt. Collect the washings and recover the starch by settling in shallow tanks; it may then be dried as a valuable by-product. Washing it off the strips is necessary because it would gelatinize in blanching, causing the dried potatoes to clump together.

Place in a continuous steam blancher for 5 to 7 minutes at about 212° F, or until the peroxidase enzyme is destroyed. Test the blanched potatoes for peroxidase frequently during the day by the method previously described. Rinse the blanched potatoes briefly under sprays of water.

Load trays at about 1 pound per square foot, spreading evenly. Dehydrate to less than 7 per cent moisture, the finishing temperature being not above 145° F.

Remove from trays and sort carefully on a slowly moving belt. For military use, pack and seal in 5-gallon, wide-mouthed cans; or in special laminated, waterproof bags of like capacity, approved by the Army.

Riced potatoes are prepared by peeling, cutting, steaming until well cooked, extruding through small holes (about $\frac{1}{16}$ inch in diameter) in a metal plate or screen onto trays, and dehydrating to less than 4 per cent moisture. The product is convenient for preparing mashed potatoes.

A typical potato-dehydrating plant, located in central California, operates on a three-shift, 24-hour basis. Potatoes are obtained from Idaho, from Klamath Lake in Oregon, and from Kern, San Joaquin, and Modoc counties. Yields of dry material per 100 pounds of fresh have been 8 pounds for the San Joaquin Valley potatoes, 10 for the Idaho, and 11 to 11.5 for the Klamath Falls. Some of the tubers are purchased on contract; others on the open market. They are generally dried within a week after receipt.

They are peeled in five Sterling abrasion peelers, the resultant gratings being washed off by sprays of water. About 42 sacks an hour, over 2 tons, are handled. Three men operate the five peelers. The waste wash water and gratings pass over a shaking screen that removes the solids, which are collected in a bin and hauled away for stock feed. The waste water goes to settling basins. The settlings, largely starch, are spread as a fertilizer.

The peeled potatoes drop onto belts, where they are trimmed by hand with sharp, spoon-shaped, tomato-coring knives. Typical losses in peeling observed were as follows: good-quality California potatoes, 13.34 per cent; California field cuts, 20.0 per cent; and Klamath egg-sized potatoes (small ones) 34.16 per cent. In trimming, losses were 14.66 per cent, 12.5 per cent, and 18 per cent of the weight of the peeled potatoes. The total losses, on a basis of per cent of the fresh potatoes, were about 35, 30, and 40 per cent respectively. The trimmings, collected in a bin, are hauled away several times daily for stock feed. A lye-peeler is being installed to replace the abrasion peelers.

The peeled, trimmed potatoes are next cut into strips, about $\frac{3}{16} \times \frac{3}{16}$ inch in cross section, in an Urschel slicer. The cut potatoes, placed on a moving woven-

wire conveyor, are sprayed with water to remove loose starch. At present the wash water and the starch are pumped to settling basins in a nearby field, and the settlings shoveled into trucks to be used as fertilizer or stock feed. This starch is of good quality. It can be recovered by settling; washed by decantation or on fine sieves; and then drained, dried, and sold for industrial or food purposes.

The washed strips are steam-blanched on a slowly traveling, woven-wire conveyor in a rectangular, plywood steam box about 6½ minutes and are then sprayed briefly with water to remove gelatinized surface starch.

They are then spread on 6 × 3 foot wooden, slat-bottomed trays, about 0.8 pound per square foot. This is very light loading.

The trays are placed on trucks, each holding 44 trays (2 stacks of 22 trays each). Every car is prominently labeled with a number and with the time of entry into the tunnel.

Four tunnels are operated, each about 65 feet long, 6 feet 6 inches high, and 6 feet 3 inches wide. Usually each is loaded with 6 or 7 double cars of potatoes. The trays rest crosswise of the tunnel.

The air is heated by two large natural gas furnaces, and the products of combustion enter the tunnels with the air. One 10-foot multivane fan handles the air for the four tunnels. The air enters at about 145° F dry-bulb and 90° wet-bulb temperature and leaves at about 125° dry-bulb and 88° to 90° wet-bulb. Since the exit air is relatively hot, drying is rapid. No spent air is intentionally recirculated, although some may find its way to the fan intake.

The drying time is 6 to 7 hours; too long exposure of the nearly dry potatoes to 145° F would cause yellowing and reddening. Enzyme tests and moisture determinations are made frequently. The dried potatoes are sorted and packed in 5-gallon cans, 10 pounds apiece. The cans are sealed and packed, two to the case, in heavy, wire-bound, wooden cases for overseas shipment. Each carload of potatoes is certified by a Food Distribution Administration inspector.

Sweet Potatoes.—At present, sweet potatoes are not dehydrated commercially in California. They may be handled like white potatoes: that is, peeled by abrasive or a 15 per cent boiling lye solution, washed, trimmed, cut in Julienne strips or in slices, rinsed, blanched in steam until cooked through, rinsed again, trayed, and dehydrated. They will stand fairly high temperatures, up to about 160° F.

Or they may be precooked in steam or in a retort until the skins will slip; then peeled, trimmed, sliced, and trayed without blanching.

Also, they may be riced like white potatoes. They keep well in flavor after dehydrating, but lose carotene rather rapidly when stored in air.

Mangels and Prescott (1921) have described the manufacture of a flour from sweet potatoes.

Pie Pumpkin and Pie Squash.—In California, at one time, considerable pumpkin flour was made commercially for pies; but its production has long since been abandoned. The Connecticut Field pumpkin and the Boston Marrow squash were used. Christie (1922) describes the process as follows: The pumpkin and squash, trimmed to remove stems and blossom point, were chopped open. The fiber and seeds were scooped out. The pieces were then shredded in a kraut slicer or sliced about ¼ inch thick in a rotary slicer or

ensilage cutter; spread on trays; dehydrated to bone dryness at a finishing temperature of 160° F; cooled; ground at once in a hammer mill; bolted on a 90-to-100-mesh screen; and sealed in friction-top cans. According to Christie it is unnecessary to peel the pumpkin and squash for making flour; but blanching for about 4 minutes in live steam gives better color, flavor, and cooking quality.

For use as a table vegetable, the pumpkin and squash should be peeled by hand. Load the trays 1½ to 1¾ pounds per square foot. Slice the pieces, and steam them 4 to 6 minutes before drying. They rehydrate well and are satisfactory for a vegetable dish or for pies.

Rhubarb.—This vegetable when dried is apt to be rather stringy and tough. Only young, tender stalks should be used—preferably red. These are trimmed; washed; cut transversely in pieces about ¾ to 1 inch long; spread on monel metal or other resistant metal screen trays; steamed 3 to 4 minutes; and dehydrated at not above 160° F to low moisture content. Or the pieces may be blanched in steam or in boiling water about 2 minutes and spread on wooden slat trays. Galvanized screen must not be used, for the acid dissolves the zinc coating. Oversteaming must be avoided; otherwise the rhubarb mats badly and sticks to the trays. The tray load is about 1 pound per square foot.

Sauerkraut.—Sauerkraut can be dehydrated very satisfactorily, stores well, and rehydrates well. It differs from fresh or canned kraut chiefly in its milder flavor, greater saltiness, and lower acidity; some acid and flavor are lost in drying. It is saltier because on refreshing and cooking it does not return fully to its original size and weight.

To prepare the sauerkraut remove outer leaves of the fresh cabbage, core, shred in a kraut slicer, mix with 2½ per cent of fine-grain dairy salt in a circular wooden vat; put the vat head in place, and apply heavy pressure. Allow to ferment until well cured—normally 4 to 6 weeks.

Drain. Blanch in live steam about 10 minutes. Spread on trays, about 1 pound per square foot. Dehydrate to less than 7 per cent moisture, finishing at not above 140° F. If desired, the juice may be concentrated in aluminum, monel metal, or nickel kettles to about 10 per cent of its original volume and then mixed with the nearly dry kraut, which absorbs it readily. The drying is then completed. This procedure improves the flavor.

The dehydration of sauerkraut should have possibilities for the civilian trade as well as for the Army.

Spinach.—The Prickly Seeded spinach grown commonly in central California for canning and for the fresh market has proved satisfactory for dehydration (fig. 21). The leafy vegetable known as New Zealand spinach also dries very well. Whether it is adapted to large-scale production for dehydration is not known; the picking of the leaves individually at intervals during the season might make the cost prohibitive.

Spinach rapidly loses its vitamin-C content after cutting (Chace, 1942) and should therefore be dehydrated promptly. Once harvested, it should not stand more than 3 or 4 hours. Trim and sort the leaves. Soak a short time in clear, cold water with air agitation, to loosen adhering soil. Wash thoroughly in a rotating drum washer with forceful sprays of cold water. Blanch in live steam, preferably on the trays, for 3 to 5 minutes (the time depending on efficiency

of the blancher) until peroxidase enzyme is destroyed. Load the trays ¾ to 1 pound per square foot. Spread evenly; avoid matting and bunching. Blanched spinach is difficult to spread. Dehydrate to less than 4 per cent moisture, finishing at not above 155° F. Spinach withstands fairly high temperatures and also lends itself well to parallel-current dehydration. It has been dried in less than two hours with excellent results by starting at 185° to 195° and finishing in dry air at 160° to 165°. Rapid drying is possible only if the spinach is not overblanched, is spread evenly, and is not piled too high on the trays.

Fig. 21.—Spinach before and after dehydration.

Dried spinach, being brittle, shatters badly under compression at room temperature. If heated to and compressed at 140° to 150° F it is less shattered. By increasing its moisture content slightly in humid air and then warming, one may compress it into slabs. These, if only ¼ to ⅜ inch thick, may then be redehydrated.

Packaging in inert gas is desirable: although spinach stored in air retains its color and vitamins A and C fairly well, it develops a haylike odor and flavor. Wetting the blanched spinach with 0.25 per cent bisulfite solution minimizes these changes.

Summer Squash, including Zuchini or Italian Squash.—These are the familiar, small, tender squash eaten fresh in the summer. They are trimmed; washed; diced; sliced about ¼ inch thick without peeling; trayed at about 1½ pounds per square foot; steamed 3 to 6 minutes; and dehydrated at not above 135° to 140° F to less than 5 per cent moisture. Both, when refreshed and cooked, are fairly satisfactory. With careful handling they may be treated in a continuous steam blancher; but if overblanched they become soft and difficult to handle.

Tomatoes.—At present tomatoes as such are not dried commercially. Considerable puree, however, is flaked by a two-stage procedure; and the flakes are ground to a powder. The tomatoes are washed thoroughly, sorted, and trimmed as for catsup. Then they are crushed; heated to boiling; pulped in a tomato pulper ("cyclone"); and put through a finisher to give a smooth, fine-grained pulp, free of seeds, skins, or coarse particles. The pulp is then concentrated in vacuum pans to about 20 per cent solids. The resulting heavy puree is dried to an almost anhydrous condition on highly polished, slowly revolving, stainless-steel drums, heated internally with steam to about 300° F. It is then scraped off by a fixed blade set at a low angle against the surface of the drum. It comes away in a sheet about as thick as wrapping paper, and when cooled by a current of cold, dry air becomes very brittle and friable. To dry it properly one must add starch or some other drying or "stabilizing" agent.

Spices may be added to give a tomato-cocktail flavor. The dry flakes are powdered by a hammer mill in an air-conditioned room of low relative humidity and sealed at once in moistureproof containers. They may be stored in moisturetight steel drums and later converted into powder; or they may be used in soups, beverages, and the like without grinding. Powdered milk mixed with powdered tomato will form the basis of soup.

The flakes and powder must be packed in vacuum or inert gas to prevent vitamin C and the tomato pigments (lycopene and carotene) from being lost by oxidation. The addition of a little sodium or potassium bisulfite before drum-drying would probably conserve most of the vitamin C and pigments even during storage in air.

In World War I, a manufacturer dried tomatoes as follows: They were sliced; lightly treated in the fumes of burning sulfur; dried to a leathery consistency; and pressed into slabs, which were then cut into bricks and wrapped.

It has proved desirable here to sulfur the sliced large tomatoes or halved small tomatoes before dehydration. They then retain their color and flavor fairly well, even in nonhermetically sealed containers.

The procedure recommended is as follows: Steam a few seconds to loosen the skins. Chill in cold water; remove the peels by hand; with large tomatoes, cut out a portion of the core at the stem end. Slice $3/16$ to $1/4$ inch thick. Spread one layer deep on wooden trays heavily coated with neutral, white mineral oil. Treat in the fumes of burning sulfur to give about 1,000 p.p.m. of SO_2 in the freshly sulfured tomatoes. Dry to less than 5 per cent moisture, finishing at not above 140° F.

In using small pear-shaped or plum-shaped Italian varieties such as the San Marzano and Principe Borghesi, peel them; cut them in half, lengthwise; and then proceed as with the sliced large tomatoes.

Peeling may be omitted in both cases, though the skins, after drying and rehydrating, are rather tough and prominent.

Dried tomatoes do not regain their original shape and size on rehydration, but remain rather badly collapsed even when soaked and cooked. They are satisfactory, however, for flavoring stews, meat loaves, and the like; also for frying after rehydration. They should be useful in England, where fried tomatoes are a popular dish.

Sliced tomatoes can be brought to about 2 per cent moisture and then

TABLE 8

SUMMARY OF PROCEDURES FOR DEHYDRATION OF VEGETABLES

Vegetable product	Preparation of vegetable for blanching	Blanching, minutes in steam	Tray load, pounds per square foot	Maximum safe finishing temperature, deg. F.	Maximum moisture content, per cent	Remarks
Asparagus tips	Tips only. Slice. Wash thoroughly	10	1½	145	5	Not very satisfactory
Asparagus (powdered)	Use tender portion only	10	1½–1¾	145	3	Hammer-mill to powder
Artichokes, Globe	Remove outer leaves, use hearts only. Cut in halves lengthwise	15	1½	145	5	0.5 per cent citric acid blanch best
Artichokes, Jerusalem	Peel by abrasion. Trim. Julienne or dice	6–8	1–1½	145	5	Can be lye-peeled
Beans, dry (precooked, plain)	Soak 10–15 hours	20–60 (until cooked)	1–1½	160–170	5	Can be pressure-blanched
Beans, dry (precooked with sauce)	Soak. Mix with Boston baked bean sauce or tomato sauce	Until cooked in sauce	1–1½	160	5	Add sauce to partially dried beans
Beans, green; lima, and broad or horse-bean (*Fava*)	Shell by machine. Sort	6–10	1–1½	145–150	5	Sort out overripe
Beans, green; string and stringless	Snip, wash, sort, cut in medium lengths	10–20	1–1¼	140	5	Cut lengthwise for rapid drying
Beets	Peel by cooking, flaming, abrasion, or lye. Julienne or dice	Whole, 30; others, 5–10	1–1½	150	5	....
Broccoli	Trim, wash, cut large stalks in half lengthwise	4–6	1–1¼	140	4	Buds shatter off
Brussels sprouts	Trim, cut in half lengthwise	4–6	1–1¾	140	4	Scorches easily. Should be sulfured.
Cabbage	Remove outer leaves and core. Shred 3/16 inch wide	2–4 on screen, 6–7 on wood	1 or less	140	4	Scorches easily. SO_2 desirable. Do not overblanch
Carrots	Scrub and wash. Lye-peel, wash, trim. Julienne or dice	6–15	1¼–1¾	155	5	Oxidizes rapidly after drying
Cauliflower	Trim, cut buds in half lengthwise. Spread cut surface upward	4–6 until catalase destroyed	1¼–1½	140	..	Avoid overblanching. Sulfuring beneficial
Celery	Scrub and wash. Trim, cut in ¼ to ½ inch lengths	1–2	1–1½	145	5	Light blanch for best flavor
Celery (powdered)	Scrub, wash, trim, slice entire stalk and leaves	0	1–1¼	145	3	Hammer-mill to powder
Celery root	Scrub, wash, peel. Julienne, dice, or slice	8–10	1¼–1½	150	5	Improved by mild sulfuring
Chard	Trim and wash	5–7	1 or less	150	5	Stems dry slowly
Chayote	Wash, trim, quarter. Slice quarters 3/8 inch thick	5–6	1–1¼	145	5	Better if peeled
Corn	Husk, trim	15–20 on cob, then cut	1–1¾	160	5	Remove silks by air suction or blast after drying

Eggplant	Wash, trim, quarter, slice 3/8 inch thick	4–5	1	150	5	May be peeled before drying
Garlic (buttons)	Separate buttons, remove husks	0	1¼–2	140	5	Dries much more rapidly if sliced. Remove husks by air suction or blast after drying
Garlic (powdered)	Separate buttons, sliced or not as desired	0	1–1½	140	3	Hammer-mill to powder. Seal airtight
Kale and miscellaneous greens	Trim, sort, wash	5–10	1 or less	140	5	Stems dry slowly
Leeks	Slice bulbs and leaves	0	1 or less	140	4	May use leaves only and get several crops from bulbs left in soil
Mushrooms	Sort, wash, remove stems	5–10	1–1¼	150	5	Peel and slice large ones; tender stems may be dried
Okra	Trim, wash, slice crosswise 3/16- to ¼-inch lengths	4–8	1–1¼	150	5	Useful in soups
Onions	Cut out root crown and top. Slice	0	1–1¼	135	4	Remove husks by air blast or suction after drying. Flaking rolls desirable
Onions (powdered)	Cut out root crown and top. Slice	0	1–1¼	135	2–4	Hammer-mill to powder. Usually only fines from flaking rolls used
Parsnips	As for carrots	6–10	1–1½	155	5	Keep better than carrots
Peas	Shell from the vine by machine, sort	5–15	1–1½	150	5	Quality grading by brine method desirable. Dry slowly near end.
Peppers and pimentos (whole)	Sort, wash	0	Varies with size	150	5	Can start at 180° F. Use low-humidity air. If for powder, dry to 2–3 per cent moisture
Peppers and pimentos (sliced)	Core, slice in about ¼-inch strips	0–6	1–1½	150	5	Can also dry cored, but unsliced
Potatoes	Wash, lye peel, wash, trim, Julienne or dice, wash	5–8	1–1¼	145	7	Can be peeled by flame or by abrasion
Potatoes (riced)	Wash, peel, trim, slice, precook, rice	Until well cooked	1	145	7	Can be precooked in skins, then peeled and riced
Sweet potatoes	Lye-peel or precook and slip skins by hand, trim, Julienne, slice, or dice	5–8 (or precook in skins)	1–1½	160	7	Can be peeled by abrasion
Pumpkin and Hubbard squash	Cut, remove seeds and rag, slice 3/16 to ¼ inch	4–6	1½–1¾	155	5	For powdering, may have to dry below 5 per cent moisture. Better if peeled
Rhubarb	Trim, cut in ¾-inch lengths	2	1	150	5	Blanch on trays
Sauerkraut	Drain	10	1	140	7	When nearly dry, mix with juice, finish drying
Spinach	Sort, wash, trim	3–5	1 or less	160	5	Handles best if blanched on trays
Squash: Zuchini, Banana	Wash, slice 3/16 inch thick or dice	3–6	1	135–140	5	Need not be peeled
Tomatoes (sliced or halved)	Scald, chill, peel, slice large tomatoes, cut small in half	0	1–2	145	5	Much better if sulfured 20 minutes in 2 per cent SO_2. May omit peeling
Tomatoes (powdered)	Wash, sort, trim, cut, boil, pulp, concentrate to 20 per cent solids, add starch or other dryer	0	0	...	2	Dry on drum drier. Hammer-mill to powder
Turnips and rutabagas	Peel by abrasion, trim, Julienne or dice	8–10	1–1½	145	5	Difficult to destroy peroxidase

converted to powder or meal by a hammer mill or a grinder. The oil of the seeds, however, may eventually become rancid unless the powder is sealed in vacuum or inert gas.

Turnips and Rutabagas.—The Quartermaster Corps includes dehydrated rutabaga turnips among the seven vegetables desired for Army use overseas, but finds that its needs are very limited, for most soldiers dislike this vegetable even when fresh.

Choose turnips or rutabagas free of woodiness. Trim off roots and leaves. Use an abrasion peeler. Cut off crowns; trim and sort. Cut in Julienne strips or in cubes. Blanch 10 minutes in live steam. Load the trays at 1¼ to 1½ pounds per square foot. Dry to less than 4 per cent moisture, finishing at not above 145° F. Packing in inert gas improves keeping quality, but is less essential than for carrots and cabbage.

THE NUTRITIVE VALUES OF DEHYDRATED VEGETABLES

A brief review of the nutritive values of dehydrated vegetables will suffice here. The vegetables fall naturally into two classes—leafy and nonleafy. The former have a low caloric value, around 25 large calories (1 Calorie, large calorie, or kilocalorie = 1,000 calories) per 100 grams, while the latter, which are usually high in starch, have a high value—80 to 120 Calories.

The leafy vegetables are valuable primarily for their bulk, their vitamins, and their mineral content. The starchy ones provide energy, vitamins, and minerals. Since dehydration and reconstitution have little effect upon their value as bulk or for energy, we need consider only the minerals and vitamins.

Minerals.—Some mineral constituents of vegetables vary greatly in dietary value. Those that can be utilized in inorganic form—such as sodium, iodine, potassium, and chloride—are of equal value, irrespective of the foods in which they occur. This statement is much less true, however, of such elements as calcium, copper, and iron. Calcium in milk, combined with protein, is much more effectively utilized by the body than calcium in spinach, where a high proportion may be found as calcium oxalate, as noted by Rau and Murty (1940). According to Shields and associates (1940), the availability of calcium in lettuce, carrots, and string beans is 85, 80, and 74 per cent, respectively, that of calcium in milk; and evidently less is present as oxalate in these vegetables. A gross analysis of the ash of a particular vegetable may, in consequence, be misleading.

Unlike the animal, the green plant builds its food with inorganic salts from the soil, and with carbon dioxide from the air. Sulfates and nitrates, for example, furnish the sulfur and nitrogen for synthesizing plant proteins; but these salts are useless for animals in this respect. The plant elaborates inorganic iron into the framework of enzymes needed in respiration; for man, however, the most effective source is liver and similar organs, where high concentrations of iron and copper in complex organic combination may be encountered. The role of the mineral elements is readily demonstrated. Lack of calcium, or iron, leads to diseases involving the bone structure, or to insufficient red-blood formation. Equally important is the role of other minerals in removing waste products. The blood must be capable of absorbing considerable carbon dioxide, formed by the burning of the foods, and transporting it in the venous blood to

the lungs, where it is given off to the air. The alkali reserve of the blood, which is the amount of base combined as bicarbonate (and is thus a measure of the CO_2-combining power of the blood), depends on the amount of alkali (base) available. Conditions known as acidosis and alkalosis are descriptive of abnormally low and high CO_2-combining capacity respectively; they arise when the delicate acid-base balance in the blood has been disturbed. To offset the effect of exercise, including changes in the alkali reserve, one must necessarily breathe faster and more deeply. Whereas the blood is slightly alkaline, pH 7.35 to 7.43, the urine is normally acid: according to physiological texts, 300 to 700 cc of N/10 acid is excreted daily. The kidneys therefore enable the blood to maintain its slightly alkaline reaction at an almost constant level by eliminating the acid, retaining as far as possible the alkali. The acid or alkaline reaction of the urine depends on the diet, the urine of herbivorous animals being normally alkaline, that of carnivores acidic.

The alkalinity of the ash from a food is a measure of the excess of base, inorganic sodium, potassium, calcium, and the like over inorganic acid (for example sulfate, chloride, and phosphate), which is unaffected by ignition, whereas ashing destroys citrates, malates, succinates, and other organic acid radicals. In general, fruits and vegetables have an alkalizing effect.

Nutritionally man's diet varies from the almost wholly carnivorous, as with Eskimos and certain African tribes, to that of the strict vegetarian; and yet man has survived. His cultural level would seem to have been influenced far more by climatic environment and by available natural resources than by diet. Nevertheless, under our more standardized environment, with respect to work and to shelter from the extremes of climate, more attention must be paid to food. The well-balanced diet is merely the one under which the average citizen thrives. It includes acid and alkaline foods because both are essential; and, for many persons, it should include more fruits and vegetables than is ordinarily the case. Beyond this we need not go here; the reader is referred to such writers as Bodansky (1930) and Sherman (1938).

The availability and proportion of minerals in the dehydrated vegetable, if blanched in steam before drying, need not be significantly less than in other forms of processing or in home cooking. Blanching in water, however, removes many water-soluble nutrients. See Magoon and Culpepper (1924); also Adam and Horner (1942).

Vitamins.—The vitamins require a fuller discussion. Those of the B group are not appreciably affected by drying. Thiamin, B_1, is destroyed by sulfuring; riboflavin, B_2, is susceptible to light. Since these are both soluble in water, blanching losses must be carefully controlled. Except with legumes, it is doubtful whether more than 10 to 25 per cent of the body's B-group requirements comes from our fruits and vegetables combined.

Provitamin A (carotene) and vitamin C (ascorbic acid) offer special problems because they are sensitive to atmospheric oxidation. The canned product usually retains a high proportion of the original amounts found in the fresh vegetable. This is frequently not the case with ascorbic acid in the dehydrated product. A shorter drying time, at 150° to 160° F, is less destructive to vitamin C than a longer period at 120°. As Cruess and Joslyn (1942) have shown, the loss of ascorbic acid in drying is largely nonenzymatic.

With equal clearness, the results of Chace (1942) indicate the importance of low moisture content for retention of ascorbic acid in storage. After 3 months at 90° F, cabbage at 3.8 per cent moisture retained five to eight times as much of the vitamin as the same cabbage at 7 per cent moisture. Recent experiments here favor the use of SO_2, at not over 1,000 to 2,000 p.p.m., if prolonged storage under adverse temperatures is contemplated. Compared with low moisture, the effect of inert gas in storage is much less pronounced. In part the reason may be incomplete removal of oxygen from the can; and this problem may prove difficult for the smaller operators. Sulfuring can be more readily controlled, and the product may then be stored in air.

Carotene is in many respects less sensitive than ascorbic acid, especially during dehydration. Blanching is, however, essential if the vegetables are to be stored for any appreciable period. Its effect on carotenoid pigments is being studied intensively. Apparently, by expelling air and causing the starch grains to burst and become gelatinized, blanching protects somewhat against subsequent oxidation during storage. Packaging in inert gas somewhat improves flavor and palatability; but prolonged storage at high temperatures always means deterioration.

In comparisons made on carrots as affected by blanching and sulfuring, after 3 months at 90° F in air, the following results were obtained, in milligrams of carotene per gram of dry carrot:

	Milligrams per gram
Unblanched, unsulfured	0.114
Blanched, unsulfured	0.452
Unblanched, sulfured	0.548
Blanched, sulfured	0.842

Whereas the unsulfured carrots had developed a haylike odor, the sulfured were free of this defect and were palatable when cooked.

Table 9 shows retention of ascorbic acid in vegetables as affected by various pretreatments. The results must be interpreted with caution. As is clear from the recent paper by Hochberg, Melnick, and Oser (1943), many loopholes exist in the chemical methods now used for determining ascorbic acid. These figures are directly comparable in one respect—namely, that all were made on dehydrated material, by direct visual titration.[11] In these samples, which were held at a moisture content below 4 per cent, in air at 90° F, no substantial proportion of ascorbic acid was converted to the oxidized form as a result of storage. The presence of carotene can be verified by several means, whereas only one property of ascorbic acid, its reducing activity, can be measured, a property not unique to this constituent in a plant extract.

According to numerous tests, unsulfured vegetables lose ascorbic acid regardless of their storage in air, vacuum, or inert gas. If 4 per cent moisture is the lowest practicable moisture level for present equipment, a combination of sulfuring and inert gas may prove even more beneficial than sulfuring alone.

If the vegetable is not blanched, it is tough when reconstituted; and if in

[11] By the photometric procedure now adopted, with 1 per cent metaphosphoric acid as extractant (Loeffler and Ponting, 1942), no major discrepancies in the older method have been found except with one batch of Savoy cabbage.

addition it has been sulfured, the taste of the SO_2 is altogether too pronounced because of the extra chewing required. In the absence of sulfur the product develops a haylike odor, especially objectionable if it has not been blanched.

With respect to palatability and retention of carotene and ascorbic acid, the combination of low moisture, blanching, and light sulfuring appears most promising. The thiamin content is necessarily impaired; but if adverse and prolonged storage is contemplated, the loss would seem unavoidable at present. Indiscriminate sulfuring of vegetables would probably not be wise. In Canada, cabbage and potatoes are said to be given a brief sulfite dip; this practice might well be extended to carrots. It would probably be unwise to sulfur legumes, because of their thiamin content.

TABLE 9

Retention of Ascorbic Acid in Stored Dehydrated Vegetables

Vegetable	Pretreatment	Milligrams ascorbic acid per gram*		Per cent retention
		Initial	After 3 months	
Tomato	Blanched	2.80	0.75	27
Cabbage	Blanched	2.80	1.46	52
Spinach	Blanched	2.09	1.20	57
Tomato	Sulfured	1.80	1.38	77
Cabbage	Sulfured	3.55	3.05	86
Spinach	Sulfured	3.89	3.00	77
Tomato	Blanched and sulfured	2.30	1.80	78
Cabbage	Blanched and sulfured	2.73	2.58	94
Spinach	Blanched and sulfured	3.96	2.80	71

* Calculated on dry-weight basis.

In general, except for a lower vitamin-C content, dehydrated vegetables should be as nutritious as similar material processed otherwise; but their storage life can usually not be rated the equivalent of the canned.

CHANGES IN INTERNAL STRUCTURE OF VEGETABLES AS A RESULT OF DEHYDRATION

Studies on the cell structure of vegetable tissues after dehydration, and also after subsequent rehydration, have been made by Reeve (1942) and by Drs. T. E. Weier and L. K. Mann (unpublished data), as revealed by the microscope.

The most intensive investigations have been made on the starch grains because these lend themselves to studies of this type. Blanching causes the starch grains to swell (gelation), sometimes filling the whole cell. Rapid blanching, where a temperature of 212° F is attained within 30 to 60 seconds, causes no further change in the starch. Weier and Mann find, however, that with some vegetables, including carrot, rutabaga, sweet potato, and parsnip, a slow blanch causes starch hydrolysis to dextrins. This is brought about by an enzyme, amylase. Although the amylase is destroyed by the high temperature

finally attained, it is active at intermediate temperatures. Consequently if a blanching belt or tray is heavily loaded, much of the material does not reach 212° for possibly 2 or 3 minutes, and sometimes even longer, and as a result the starch is hydrolysed. They have found great variation in the starch content of a given carrot variety, from supposedly pure strains pulled from the same test plot.

Starch in potatoes, however, does not show hydrolysis, apparently because the amylase in potatoes is destroyed before the starch has gelled.

They have shown by these studies that many dehydrators producing carrots blanch slowly as indicated by the condition of the starch. A few samples indicate more rapid blanching. The practical consequences are not yet known, but it is of great interest to know that internal evidence provides clues as to the operation of the blancher for carrots and some other vegetables.

TABLE 10

DEHYDRATION AND REHYDRATION RATIOS FOR SEVERAL VEGETABLES

Vegetable	Drying ratio	Rehydration ratio (without cooking)	Rehydration ratio (after cooking)	Rehydration ratio (after cooking)*	Rehydration ratio (after cooking)†
Beets	10 : 1	1 : 5.5	1 : 6.5	1 : 7	1 : 6.6
Broccoli	8 : 1	1 : 6.5	1 : 7.4	.....	......
Cabbage	14 : 1	1 : 5	1 : 8.1	1 : 8.5	1 : 10.7
Carrots	9 : 1	1 : 5	1 : 6	1 : 5.75	1 : 5
Corn	3 : 1	1 : 3.2	1 : 3.4	......	......
Onions	9 : 1	1 : 6.6	1 : 6.5	1 : 6	1 : 6.9
Peas	4 : 1	1 : 3	1 : 3.6	......	......
Potatoes, white	5.2 : 1	1 : 3	1 : 4.8	1 : 3.67	1 : 6
Potatoes, sweet	4 : 1	1 : 3.6	1 : 4.1	1 : 3	1 : 2.6
Sauerkraut	17 : 1	1 : 10	1 : 11	......	......
Spinach	15 : 1	1 : 5	1 : 6.3	......	1 : 6.9
String beans, pole	11 : 1	1 : 4.5	1 : 5.7	......	......
String beans, bush	6.8 : 1	1 : 4.7	1 : 5.8	......	......
Tomatoes, sliced	15 : 1	1 : 6.5	1 : 7	......	......

* After Logan (1942).
† After Chace (1942).

Carotene is present in various forms in the raw carrot, but is dissolved rapidly in oil droplets as a result of blanching and also as a result of drying without pretreatment.

Studies of this sort should improve the quality, particularly upon storage; and further work may be expected to provide a basis for practical modifications in some of the operating conditions.

REHYDRATION RATIOS

Dehydrated vegetables do not fully regain, on rehydration and cooking, the size and form of the blanched, fresh vegetables. Most of them, on the other hand, do attain a reasonably attractive appearance and lose most of the shriveled condition. There is considerable variation in the rehydration ratios (weight of rehydrated compared with weight of dehydrated) for most vegetables, occasioned by variety, maturity, and general condition of the raw material and by the method of processing and dehydration. Consequently, the rehydration ratios given in table 10 are only approximate.

The rehydration weight should be compared with the weight of the cooked vegetable, rather than the raw, since changes in drained weight occur in cooking fresh vegetables. For comparison there appear in table 10 values for several of the dehydrated vegetables after cooking, as published by Chace (1942) and by Logan (1942).

In a recent experiment, 100-gram lots were cooked fresh, and the loss in drained weight noted; and other 100-gram portions were prepared in the usual ways, dehydrated, rehydrated, weighed, cooked, and again weighed, with the results shown in table 11. The table gives the weights of the vegetables when rehydrated (soaked) and when cooked after rehydration, in various experiments. As previously noted, these weights will vary considerably with the variety, the maturity, the season, and other factors; the figures given are at best only approximate.

TABLE 11

EFFECT OF DEHYDRATION ON THE WEIGHT OF SIX VEGETABLES*

Vegetable	Fresh, after cooking	Soaked, after dehydration	Soaked and cooked, after dehydration
	grams	*grams*	*grams*
Broccoli	98	68	79
Cabbage	93	56	63
Carrots	90	75	80
Onions	..	51	61
Potatoes	105	105	109
Spinach	98	51	63

* Equivalent to 100 grams raw in all cases.

There is fair agreement among the three laboratories, probably well within the natural variation in the raw materials. Clearly, most of the dehydrated products do not regain, on cooking, the weight of the prepared, fresh, raw vegetables. The cooked dehydrated vegetables therefore have a higher concentration of soluble solids than the cooked fresh ones, a fact that partly explains the differences in flavor of the two. Dried spinach, for example, tastes brackish after rehydration and cooking, probably because of its high content of salts; cooked dehydrated carrots taste sweeter than the cooked fresh carrots; and dried sauerkraut on cooking is much saltier than the cooked fresh kraut, for the reason given above.

GOVERNMENT REGULATIONS AND SPECIFICATIONS[12]

State and Federal food and drug regulations, together with those of the State Board of Health, require that food-dehydrating establishments be kept clean and sanitary. Several plants have been closed temporarily because their liquid wastes have created offensive odors. The State Fish and Game Commission forbids putrescible factory effluents to be poured into streams that contain fish.

The most important regulations, however, are those of the Army and of the

[12] Details may be secured by dehydrater operators from the Food Distribution Administration in San Francisco or in Washington, D. C. Only a summary of the U. S. Army specifications is presented here.

Food Distribution Administration. Specifications, revised in September, 1942, are in effect for beets, cabbage, carrots, onions, sweet potatoes, white potatoes, yellow turnips (rutabagas), dried baked beans, soup mixes, and dried tomato cocktail.

Beets.—Beets must be free from woodiness and light-colored rings. They may be sliced ⅛ to ¼ inch thick; cubed $\frac{3}{16}$ to ⅜ inch in diameter; or cut in Julienne strips not less than $\frac{3}{16}$ nor more than ⅜ inch wide and not less than ¾ inch long. The grade must be no. 1 except for size. They must be blanched sufficiently to destroy peroxidase. The finishing temperature must not be above 150° F. There must not be more than 2 per cent defective pieces nor more than 5 per cent moisture. They must cook adequately in 30 minutes' boiling. Containers need not be hermetic.

Cabbage.—Cabbage must be of no. 1 grade except for size; may come in shreds ⅛ to ¼ inch in width; may be green or white; must be blanched until midribs are translucent and catalase is destroyed; but may show slight positive peroxidase test. Not more than 15 per cent may pass through an 8-mesh standard sieve. There must not be more than 2 per cent of defective pieces, nor more than 4 per cent moisture. The product must rehydrate to approximately original form in water in 30 minutes at 68° F. Packing must be in inert gas such as CO_2 or nitrogen.

Carrots.—Slices, cubes, or Julienne strips are acceptable; size requirements are the same as for beets. The grade must be no. 1 except for size. The carrots must be blanched in live steam until peroxidase is destroyed. The maximum finishing temperature is 160° F. Not more than 10 per cent of the strips may be less than ¾ inch long. Not over 2 per cent of defective pieces will be permitted. Moisture must not exceed 5 per cent. The carrots must rehydrate to approximately original form and color within 30 minutes after coming to a boil. Packing must be in inert gas such as CO_2 or nitrogen.

Onions.—Onions are sliced or flaked, the slices being not less than ⅛ nor more than ¼ inch thick; or they may be powdered. The grade must be no. 1 except for size. White Portugal, Ebenezer, Southport White Globe, Southport Yellow Globe, or similar varieties are acceptable; but not sweet, mildly flavored, or bitter onions. There is no blanching. The finishing temperature is not over 140° F. Not more than 2 per cent of the sliced form may pass through a standard 8-mesh sieve. Moisture must not exceed 4 per cent. The onions must rehydrate to approximately original form in 30 minutes' boiling. They need not be packed in inert gas.

Potatoes.—These may be sliced, cubed, or cut in Julienne strips, of the same sizes required for beets. They may also be powdered or riced. Use no. 2 grade or better except for size. Choose a variety that will be white and mealy, not soggy or discolored, after cooking. Blanch in live steam until free of peroxidase; keep the finishing temperature below 150° F, the moisture content under 7 per cent. Defects must not exceed 2 per cent. Julienne strips must cook in 10 minutes' boiling in 4 to 6 parts of water. Potatoes need not be packed in inert gas.

Sweet Potatoes.—These are sliced, cubed, cut in Julienne strips, riced, or powdered. The sizes of pieces are the same as for beets. The grade must be at least no. 2, except for size. The moist or yam type is preferred. Blanch until

peroxidase is destroyed; keep the finishing temperature below 165° F, the moisture under 7 per cent. Strips and powder must rehydrate properly in 10 minutes' boiling; slices or cubes in 30 minutes. Defects must not exceed 2 per cent. Sweet potatoes need not be packed in inert gas.

Rutabagas.—Sliced, cubed, or Julienne strips are acceptable, as for beets. The grade must be no. 1 except for size. Blanch until peroxidase is destroyed. Keep the finishing temperature below 160° F; the number of defective pieces below 2 per cent; the moisture below 5 per cent. Rutabagas must rehydrate properly in 30 minutes' boiling. They need not be packed in inert gas.

Baked Beans.—Use dry beans of Federal Specification JJJ–B–106. Salt, sweeten, and spice according to specifications SS–S–31, EE–S–631, and JJJ–S–791. Use hydrogenated fat, with an oxygen-keeping test of 100 hours' minimum, and flavor retention at 400° F. Add no meat. Cook and bake to full edibility before drying; do not mash. The color must be a uniform, characteristic brown; the moisture not over 6 per cent. The beans must rehydrate in 15 minutes when prepared according to label directions. They need not be packed in inert gas.

Soup Mixtures.—Specifications have been issued for the following soups: (a) mixed vegetable, (b) yellow pea, (c) green pea, (d) bean (navy and the like), (e) cream of tomato, (f) soup paste with chicken flavor, and (g) powdered cream of cheese soup. The tomato soup must not contain more than 1 per cent moisture; the cheese soup not more than 5 per cent moisture; the others not over 7 per cent. Soups must rehydrate free of rancidity, bitterness, mustiness, and other undesirable flavors and odors. Tomato or cheese soup must be packed in hermetic containers; the others may be in moistureproof bags.

Tomato-Juice Cocktail.—This is made from Grade-A puree, with sugar, salt, spices, and stabilizer added, but no artificial color. The moisture must not exceed 5 per cent. The product must rehydrate well in water in 5 minutes. It is vacuum-packed in no. 10 cans, 3 pounds per can, and may be flaked or powdered.

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